A SYNOPSIS

OF THE

SCIENTIFIC WRITINGS

OF

SIR WILLIAM HERSCHEL

PREPARED BY

EDWARD S. HOLDEN AND CHARLES S. HASTINGS.

[FROM THE SMITHSONIAN REPORT FOR 1880.]

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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A SYNOPSIS

OF THE SCIENTIFIC WRITINGS OF SIR WILLIAM HERSCHEL.

BY EDWARD S. HOLDEN AND CHARLES S. HASTINGS.

I.—INTRODUCTORY NOTE.

The astronomical life of Sir WILLIAM HERSCHEL covered forty-two years. During this period he published no less than sixty-nine different memoirs, which are scattered through the annual volumes of the Philosophical Transactions of the Royal Society of London from 1780 to 1818.

Two generations have passed since his death, and we have no readier means of studying his works than in the original volumes of the Transactions, now become rare and costly. Students of astronomy and physics are thus often compelled to know his writings at second-hand from text-books, and not in the vigorous and ardent style of the original. The text-books also frequently quote him incorrectly, and have thus helped to spread erroneous notions not only of what he said, but of the facts themselves.

HERSCHEL'S long life was all too short, and his assistance was too small to allow him to put even his published work into a final definite form. He has once given us a hint of what he desired, and it seems scarcely less than a duty for his successors to carry out his wishes.

At the end of his memoir of 1811, HERSCHEL added a synopsis of its contents made paragraph by paragraph; this synopsis (which is given at pages 87–89 of this work) serves to summarize and to enforce his views, and to condense his arguments. His style lends itself to this condensation. The synopsis of 5 pages contains all the material facts of the main paper of 67 pages, and the course of the argument can be plainly followed.

In the absence of an edition of HERSCHEL'S collected works, a want whose fulfillment still seems far off, we have thought that we could hardly render a better service than to carry out for all of his writings the idea which he executed for only one. The model has been set by himself. We have simply followed this, and have given a synopsis of each of his memoirs in the Philosophical Transactions, following his own plan. The papers on astronomical subjects have been condensed by Professor HOLDEN; those on physics by Dr. HASTINGS. The works of HERSCHEL published elsewhere have not been included in the synopsis, as they are comparatively unimportant.

It is not supposed that such synopses as these will replace the original memoirs for the professional astronomer and physicist. The works of a great philosopher to be truly mastered must be studied in the form in which he gave them. Yet those who are most familiar with the originals will find the present volume most valuable.

The full subject-index will direct attention to special points. It is hoped that the work in its present form will be of service in various ways, which do not need suggestion here.

EDWARD S. HOLDEN.
CHARLES S. HASTINGS.

WASHINGTON, *October*, 1880.

II.—LIST OF THE PUBLISHED WRITINGS OF WILLIAM HERSCHEL ON ASTRONOMICAL SUBJECTS.

[IN CHRONOLOGICAL ORDER.]

[N. B. In general, translations and abstracts of these which appeared in periodicals are not noticed here. We have made exceptions in the more important cases.]

[Solution of a prize question.]
Ladies' Diary, 1799.

Astronomical observations on the periodical star in *Collo Ceti*.
Phil. Trans., 1780, p. 338.

Astronomical observations relating to the mountains of the moon.
Phil. Trans., 1780, p. 507.

Astronomical observations on the rotation of the planets round their axes, made with a view to determine whether the earth's diurnal motion is perfectly equable.
Phil. Trans., 1781, p. 115.

Account of a comet. [Dated 13th March, 1781. This was *Uranus*.]
Phil. Trans., 1781, p. 492.

On the parallax of the fixed stars.
Phil. Trans., 1782, p. 82.

Catalogue of double stars.
Phil. Trans., 1782, p. 112; translation in *Bode's Jahrbuch*, 1786, p. 187.

Description of a lamp micrometer and the method of using it.
Phil. Trans., 1782, p. 163.

A paper to obviate some doubts concerning the great magnifying powers used.
Phil. Trans., 1782, p. 173.

A letter from WILLIAM HERSCHEL, Esq., F. R. S., to Sir JOSEPH BANKS, *Bart.*, P. R. S.
Phil. Trans., 1783, p. 1.

Aus einem Schreiben des Hrn. HERSCHEL an mich [BODE], datirt London, den 13ten August, 1783.
[This is a letter forwarding HERSCHEL's memoir on the Parallax of the Fixed Stars, etc.]
Bode's Jahrbuch, 1786, p. 258.

On the diameter and magnitude of the *Georgium Sidus*, with a description of the dark and lucid disk and periphery micrometers.
Phil. Trans., 1783, p. 4.

On the proper motion of the sun and solar system, with an account of several changes that have happened among the fixed stars since the time of Mr. FLAMSTEED.
Phil. Trans., 1783, p. 247. *Bode's Jahrbuch*, 1787, p. 194, p. 224.

Astronomische Nachrichten und Entdeckungen aus einem französischen Schreiben desselben an mich [BODE], datirt Datchet nahe bey Windsor, den 18 May, 1784.
[This letter is on the subject of the use of high magnifying powers, and gives a *résumé* of his recent papers.]
Bode's Jahrbuch, 1787, p. 211.

On the remarkable appearances at the polar regions of the planet *Mars*, the inclination of its axis, the position of its poles, and its spheroidical figure; with a few hints relating to its real diameter and atmosphere.
Phil. Trans., 1784, p. 233.

Account of some observations tending to investigate the construction of the heavens.
Phil Trans., 1784, p. 437.

[*Bode's Jahrbuch*, 1788, p. 246, has a summary of this paper by Baron von ZACH. See also, *Bode's Jahrbuch*, 1794, p. 213.]

Catalogue of double stars.
Phil. Trans., 1785, p. 40.

On the construction of the heavens.
Phil. Trans., 1785, p. 213. *Bode's Jahrbuch*, 1788, p. 238. See also *same*, 1787, p. 213, and 1794, p. 213.

Aus einem Schreiben des Hrn. HERSCHEL an mich [BODE], datirt Clay Hall, nahe bey Windsor, den 20 Jul., 1785.
[This is a letter forwarding two memoirs, and giving the prices of telescopes.]
Bode's Jahrbuch, 1788, p. 254.

Catalogue of one thousand new nebulæ and clusters of stars.
Phil. Trans., 1786, p. 457. *Bode's Jahrbuch*, 1791, p. 157, and *same*, 1794, p. 213.

Investigation of the cause of that indistinctness of vision which has been ascribed to the smallness of the optic pencil.
Phil. Trans., 1786, p. 500.

Remarks on the new comet [1786, II].
Phil. Trans., 1787, p. 4.

[Letter from HERSCHEL to BODE on the discovery of two satellites to *Uranus*, dated Slough, 1787, Feb. 11.]
Bode's Jahrbuch, 1790, p. 253.

An account of the discovery of two satellites revolving round the *Georgian planet*.
Phil Trans., 1787, p. 125. *Bode's Jahrbuch*, 1791, p. 255.

An account of three volcanoes in the moon.
Phil. Trans., 1787, p. 229. *Bode's Jahrbuch*, 1791, p. 255.

Note on M. MÉCHAIN'S comet. [1787, I.] [Added to preceding paper.]
Phil. Trans., 1787, p. 232.

On the *Georgian planet* and its satellites.
Phil. Trans., 1788, p. 364. *Bode's Jahrbuch*, 1793, p. 104.

Observations on a comet [1788, II.].
Phil. Trans., 1789, p. 151.

Catalogue of a second thousand of new nebulæ and clusters of stars, with a few introductory remarks on the construction of the heavens.
Phil. Trans., 1789, p. 212. *Bode's Jahrbuch*, 1793, p. 150. Also *same*, 1794, p. 150.

Account of the discovery of a sixth and seventh satellite of the planet *Saturn*, with remarks on the construction of its ring, its atmosphere, its rotation on an axis, and its spheroidical figure.
Phil. Trans., 1790, p. 1. *Bode's Jahrbuch*, 1793, p. 239; *same*, 1796, p. 88; 1797, p. 249.

On the satellites of the planet *Saturn*, and the rotation of its ring on an axis.
Phil. Trans., 1790, p. 427.

On nebulous stars properly so called.
Phil. Trans., 1791, p. 71. *Bode's Jahrbuch*, 1801, p. 128.

On the ring of *Saturn* and the rotation of the fifth satellite upon its axis.
Phil. Trans., 1792, p. 1. *Bode's Jahrbuch*, 1796, p. 88.

Miscellaneous observations:
[Account of a comet], p. 23 [1792, I.].
[On the periodical appearance of *o Ceti*], p. 24.
[On the disappearance of the 55th *Herculis*], p. 26.
[Remarkable phenomenon in an eclipse of the moon], p. 27.
Phil. Trans., 1792, p. 23.

Observations on the planet *Venus*.
Phil. Trans., 1793, p. 201.

Observations of a quintuple belt on the planet *Saturn*.
Phil. Trans., 1794, p. 28. *Bode's Jahrbuch*, 1798, p. 90.

Account of some particulars observed during the late eclipse of the sun. [1793, September 5th.]
Phil. Trans., 1794, p. 39.

On the rotation of the planet *Saturn* upon its axis.
Phil. Trans., 1794, p. 48. *Bode's Jahrbuch*, 1798, p. 74.

On the nature and construction of the sun and fixed stars.
Phil. Trans., 1795, p. 46. *Bode's Jahrbuch*, II. Suppl. Band, p. 65.

Description of a forty-foot reflecting telescope.
Phil. Trans., 1795, p. 347. *Bode's Jahrbuch*, III. Suppl. Band, p. 238.

Additional observations on the comet. [1796, I.]
Phil. Trans., 1796, p. 131.

On the method of observing the changes that happen to the fixed stars; with some remarks on the stability of the light of our sun. To which is added a catalogue of comparative brightness for ascertaining the permanency of the luster of stars.
Phil. Trans., 1796, p. 166. *Bode's Jahrbuch*, 1809, p. 201.

On the periodical star *α Herculis;* with remarks tending to establish the rotary motion of the stars on their axes; to which is added a second catalogue of the comparative brightness of the stars.
Phil. Trans., 1796, p. 452. *Bode's Jahrbuch*, 1809, p. 201.

A third catalogue of the comparative brightness of the stars, with an introductory account of an index to Mr. FLAMSTEED'S observations of the fixed stars, contained in the second volume of the Historia Cœlestis. To which are added several useful results derived from that index.
Phil. Trans., 1797, p. 293. *Bode's Jahrbuch*, 1810, p. 143.

Observations of the changeable brightness of the satellites of *Jupiter*, and of the variation in their apparent magnitudes, with a determination of the time of their rotatory motions on their axes. To which is added a measure of the diameter of the second satellite, and an estimate of the comparative size of all the four.
Phil. Trans., 1797, p. 332. *Bode's Jahrbuch*, 1801, p. 103.

On the discovery of four additional satellites of the *Georgium Sidus*. The retrograde motion of its old satellites announced, and the cause of their disappearance at certain distances from the planet explained.
Phil. Trans., 1798, p. 47. *Bode's Jahrbuch*, 1801, p. 231.

A fourth catalogue of the comparative brightness of the stars.
Phil. Trans., 1799, p. 121. *Bode's Jahrbuch*, 1810, p. 143.

On the power of penetrating into space by telescopes, with a comparative determination of the extent of that power in natural vision, and in telescopes of various sizes and constructions, illustrated by select observations.

Phil. Trans., 1800, pp. 49–85. *Bode's Jahrbuch*, 1804, p. 231.

Investigation of the powers of the prismatic colors to heat and illuminate objects, with remarks that prove the different refrangibility of radiant heat. To which is added an inquiry into the method of viewing the sun advantageously with telescopes of large apertures and high magnifying powers.

Phil. Trans., 1800, pp. 255–283. *Bode's Jahrbuch*, 1804, p. 89.

Experiments on the refrangibility of the invisible rays of the sun.

Phil. Trans., 1800, pp. 284–292. *Bode's Jahrbuch*, 1804, p. 89.

Experiments on the solar and on the terrestrial rays that occasion heat, with a comparative view of the laws by which light and heat, or rather the rays that occasion them, are subject, in order to determine whether they are the same or different.

Phil. Trans., 1800, pp. 293–326, 437–538. *Gilbert Annal.*, X. (1802), pp. 68–78; *same*, XII. (1803), pp. 521–546.

Observations tending to investigate the nature of the sun, in order to find the causes or symptoms of its variable emission of light and heat, with remarks on the use that may possibly be drawn from solar observations.

Phil. Trans., 1801, pp. 265–318. *Bode's Jahrbuch*, 1805, p. 218, and 1806, p. 113.

Ueber den 7 Nebelfleck der 1sten Classe des Herschel'schen Verzeichniss, und über *Ceres* und *Pallas*, vom Herrn Doctor HERSCHEL, aus zwey Briefen desselben.

Bode's Jahrbuch, 1805, p. 211.

Additional observations tending to investigate the symptoms of the variable emission of the light and heat of the sun, with trials to set aside darkening glasses by transmitting the solar rays through liquids, and a few remarks to remove objections that might be made against some of the arguments contained in the former paper.

Phil. Trans., 1801, pp. 354–362.

Observations on the two lately discovered celestial bodies [*Ceres and Pallas*].

Phil. Trans., 1802, pp. 213–232. *Nicholson Journal*, IV. (1808), pp. 120–130, 142–148.

Catalogue of five hundred new nebulæ, nebulous stars, planetary nebulæ, and clusters of stars, with remarks on the construction of the heavens.

Phil. Trans., 1802, pp. 477–528. *Bode's Jahrbuch*, 1807, p. 113.

Observations of the transit of *Mercury* over the sun's disk, to which is added an investigation of the causes which often prevent the proper action of mirrors.

Phil. Trans., 1803, pp. 214–232.

Account of the changes which have happened during the last twenty-five years in the relative situation of double stars, with an investigation of the cause to which they are owing.

Phil. Trans., 1803, pp. 339–382. *Bode's Jahrbuch*, 1808, pp. 154–178.

Continuation of the account of the changes that have happened in the relative situation of double stars.

Phil. Trans., 1804, pp. 353–384. *Bode's Jahrbuch*, 1808, p. 226.

Aus einem Schreiben des Herrn Doctor HERSCHEL, datirt Slough bey Windsor, den 31 May, 1804.

[Relates to his theory of the relation between the solar radiation and the price of wheat.]

Bode's Jahrbuch, 1808, p. 226.

Experiments for ascertaining how far telescopes will enable us to determine very small angles, and to distinguish the real from the spurious diameters of celestial and terrestrial objects, with an application of the results of those experiments to a

series of observations on the nature and magnitude of Mr. HARDING'S lately discovered star [*Juno*, (1804)].

Phil. Trans., 1805, pp. 31-70.

On the direction and velocity of the motion of the sun and solar system.

Phil. Trans., 1805, pp. 233-256. *Bode's Jahrbuch*, IV. Suppl. Band, p. 67.

Observations on the singular figure of the planet *Saturn*.

Phil. Trans., 1805, pp. 272-280. *Bode's Jahrbuch*, 1809, p. 197.

On the quantity and velocity of solar motion.

Phil. Trans., 1806, pp. 205-237. *Bode's Jahrbuch*, 1811, p. 224.

Observations and remarks on the figure, climate, and atmosphere of *Saturn* and its ring.

Phil. Trans., 1806, pp. 455-467. *Gilbert Annal.*, XXXIV. (1810), pp. 82-105. *Bode's Jahrbuch*, 1810, p. 228.

Experiments for investigating the cause of the colored concentric rings discovered by Sir I. NEWTON between two object glasses laid one upon another.

Phil. Trans., 1807, pp. 180-233. *Annal. de Chimie*, LXX. 1809, pp. 154-181, 293-321; *same*, LXXI. 1809, pp. 5-40.

Observations on the nature of the new celestial body [*Vesta*] discovered by Dr. OLBERS, and of the comet which was expected to appear last January in its return from the sun. [1806, II.]

Phil. Trans., 1807, pp. 260-266.

Observations of a comet [1807, I.] made with a view to investigate its magnitude and the nature of its illumination, to which is added an account of a new irregularity lately perceived in the apparent figure of the planet *Saturn*.

Phil. Trans., 1808, pp. 145-163. *Gilbert Annal.*, XXXVI. (1810), pp. 389-393. *Zach Monat. Corresp.*, XX. (1809), pp. 512-514.

Continuation of experiments for investigating the cause of colored concentric rings and other appearances of a similar nature.

Phil. Trans., 1809, pp. 259-302.

Supplement to the first and second part of the paper of experiments for investigating the cause of colored concentric rings between object glasses, and other appearances of a similar nature.

Phil. Trans., 1810, pp. 149-177. *Gilbert Annal.*, XLVI., 1814, pp. 22-79.

Astronomical observations relating to the construction of the heavens, arranged for the purpose of a critical examination, the result of which appears to throw some new light upon the organization of the celestial bodies.

Phil. Trans., 1811, pp. 269-336. *Journ. de Phys.*, LXXV., 1812, pp. 121-167.

Observations of a comet, with remarks on the construction of its different parts. [1811, I.]

Phil. Trans., 1812, pp. 115-143. *Journ. de Phys.*, LXXVII., 1813, pp. 125-135. *Zach Monat. Corresp.*, XXVIII., 1813, pp. 455-469, 558-568. *Bode's Jahrbuch*, 1816, p. 185.

Observations of a second comet, with remarks on its construction. [1811, II.]

Phil. Trans., 1812, pp. 229-237. *Nicholson Journ.*, XXXV., 1813, pp. 193-199. *Bode's Jahrbuch*, 1816, p. 203.

Astronomical observations relating to the sidereal part of the heavens, and its connection with the nebulous part, arranged for the purpose of a critical examination.

Phil. Trans., 1814, pp. 248-284. *Bode's Jahrbuch*, 1818, pp. 97-118.

A series of observations of the satellites of the *Georgian Planet*, including a passage through the node of their orbits, with an introductory account of the telescopic apparatus that has been used on this occasion, and a final exposition of some calculated particulars deduced from the observations.

Phil. Trans., 1815, pp. 293-362. *Bode's Jahrbuch*, 1819, pp. 232-242.

Astronomical observations and experiments tending to investigate the local arrangement of the celestial bodies in space, and to determine the extent and condition of the Milky Way.
Phil. Trans., 1817, pp. 302–331. *Bode's Jahrbuch*, 1821, p. 149.

Astronomical observations and experiments selected for the purpose of ascertaining the relative distances of clusters of stars, and of investigating how far the power of our telescopes may be expected to reach into space, when directed to ambiguous celestial objects.
Phil. Trans., 1818, pp. 429–470.

On the places of one hundred and forty-five new double stars (1821).
Mem. Roy. Ast. Soc., I., 1822, pp. 166–181.

III.—List of Works Relating to the Life and Writings of William Herschel.

[Arranged Alphabetically by Authors.]

[N. B. In general, the notices of his life to be found in encyclopædias of biography, etc., are not included here.]

Arago (F.)
Analyse de la vie et des travaux de Sir William Herschel [from *Annuaire du Bureau des Longitudes*, 1842]. Paris, 1843. 18mo.
[See also the *Annuaire* for 1834, for an account of Herschel's work on double stars.]

Arago (F.)
Biographies of Distinguished Scientific Men. Translated by Admiral W. H. Smyth, Rev. B. Powell, and Robert Grant, Esq. Herschel.
First series, p. 258. Boston, 1859. 8vo.

Arago (F.)
Herschel. [Translated from the French.]
Smithsonian Report. 1870, p. 197. 8vo.

Auwers (A.)
William Herschel's Verzeichnisse von Nebelflecken und Sternhaufen bearbeitet von A. Auwers.
From the *Königsberg Observations*. 1862. Folio.

Bessel (F. W.)
Sir William Herschel. [From the *Königsberger Allgemeine Zeitung*, 1, 1843, No. 37, *et seq.*, reprinted in his] *Abhandlungen*, vol. iii., p. 468. Leipzig, 1876. 4to.

Bruhns (C.)
Karoline Lucretia Herschel, aus der *Allgem. Deutschen Biographie*. 1877, 8vo.

D'Arrest (H. L.)
Verzeichniss von Sir William Herschel's Nebelflecken *erster* und *vierter* Classe, aus den Beobachtungen berechnet und auf 1850 reducirt.
Abhandlungen d. Math. Phys. Classe der K. Sächs. Gesell. d. Wissenschaften Band iii [1857] p. 359.

Dunkin (E.)
Obituary Notices of Astronomers, p. 86.
Sir William Herschel, K. C. H., F. R. S., 1738, 1822.
London, 1879. 12mo.

Fétis (F. J.)

Biographie universelle des musiciens [article, HERSCHEL.]
Paris, 1835–37. 8vo.

Forbes (J. D.)

Sir WILLIAM HERSCHEL [being § 2 of Dissertation vi.]
Encyclopædia Britannica, eighth edition. Vol. I, *Dissertations*, p. 838.

Fourier (J.)

Éloge historique de Sir WILLIAM HERSCHEL, prononcé dans la séance publique de l'Académie royale des sciences le 7 Juin, 1824.
Histoire de l'Académie Royale des Sciences de l'Institut de France, tome vi., *année* 1823, p. lxi.

Harding (C. L.)

Des Herrn Dr. HERSCHEL'S Untersuchungen über die Natur der Sonnenstrahlen, aus dem englischen übersetzt. Erstes Heft. [Translations from *Phil. Trans.*, 1800.] Celle, 1801. 16mo.

Herschel (Carolina.)

An Account of a new Comet. [1786, II.]
Phil. Trans., 1787, vol. 77, p. 1.

Herschel (Carolina.)

An Account of the Discovery of a Comet. [1793, I.]
Phil. Trans., 1794, vol. 84, p. 1.

Herschel (Carolina.)

An Account of the Discovery of a Comet. [1795, II.]
Phil. Trans., 1796, vol. 86, p. 131.

Herschel (Carolina.)

Catalogue of Stars taken from FLAMSTEED'S observations contained in the second volume of his Historia Cælestis, and not inserted in the British Catalogue; to which is added a collection of errata which should be noticed in the same volume; with remarks by W. HERSCHEL. London, 1798. Folio.

Herschel (Carolina.)

Verzeichniss von 74 Sternen FLAMSTEEDS von denen keine Beobachtungen in der *Hist. Cœl. Brit.* vorkommen.
Bode's Jahrbuch, 1806, p. 255.

[Herschel (Carolina.)]

[Notice of her life.]
Monthly Notices Roy. Ast. Soc. vol. 8, p. 64; *also Memoirs Roy. Ast. Soc.*, vol. 17, p. 120.

Herschel (Carolina.)

Memoir and Correspondence of CAROLINE HERSCHEL. By Mrs. JOHN HERSCHEL. With portraits. London, 1876. 12mo.

Herschel (J. F. W.)

Article *Telescope*, in Encyclopædia Britannica, eighth edition. [This article (illustrated) gives most of the important features of Sir WILLIAM HERSCHEL'S manner of grinding and polishing specula.]

Herschel (J. F. W)

Catalogue of Nebulæ and Clusters of Stars. [General and systematic reduction of all Sir W. HERSCHEL'S observations brought into connection with all other similar ones.]
Phil. Trans., 1864. Page 1. 4to.

Herschel (J. F. W.)

A synopsis of all Sir WILLIAM HERSCHEL'S micrometrical measurements, etc., of Double Stars, together with a Catalogue of those Stars . . . for 1880.
Mem. Roy. Ast. Soc., vol. xxxv, p. 21. London, 1867. 4to.

Herschel (J. F. W.)

Additional Identifications of Double Stars in the Synoptic Catalogues of Sir WILLIAM HERSCHEL'S Micrometrical Measurements, etc.

Monthly Notices Roy. Ast. Soc., vol. xxviii, p. 151. London, 1868. 8vo.

Herschel (Mrs. John,)

Memoir and Correspondence of CAROLINE HERSCHEL. With portraits. London, 1876. 12mo.

Herschel (W.)

[Solution of a prize question.]

Ladies' Diary, 1779.

Herschel (W.)

The favorite Eccho Catch . . . and the preceding Glee [by S. LEACH]. To which is added the . . . Catch Sung by Three Old Women . . . in the Pantomime called "The Genius of Nonsense" [by H. HARRINGTON].

London, 1780 (?) Obl. folio.

Herschel (W.)

Göttingen Magazin der Wissenchaften und Literatur (1783), vol. iii, p. 4. LICHTENBERG AND FORSTER, Editors.

[Letter from HERSCHEL, giving a brief account of his life.]

Herschel (W.)

I. *Manuscripts in possession of the Royal Society.*

1. A series of register sheets in which are entered up *all* the observations of *each* nebula, copied *verbatim* from the sweeps. 2. A similar set of register sheets for MESSIER'S nebulæ. 3. A general index of the 2,508 nebulæ of W. HERSCHEL; given the class and number, to find the general number. 4. An index list; given the general number, to find the class and number. 5. A more complete list, like 4. 6. A manuscript catalogue of all the nebulæ and clusters, reduced to 1800 and arranged in zones of 1° in polar distance; by Miss CAROLINA HERSCHEL. 7. The original sweeps with the 20-foot reflector at Slough, in three small quarto and four folio vols. of MSS.

II. *Manuscripts in possession of the Royal Astronomical Society.*

This library contains "the whole series of autograph observations of each double star [observed by HERSCHEL], brought together on separate sheets, by Sir WILLIAM HERSCHEL and Miss CAROLINA HERSCHEL."

[Herschel (W.)]

Some account of the life and writings of WILLIAM HERSCHEL, Esq. [With a portrait.]

The *European Magazine and London Review* for January, 1785. 8vo.

[Herschel (W.)]

Edinburgh Review, vol. i, p. 426.

[A review of HERSCHEL'S memoir "Observations on the two lately discovered bodies," from *Phil. Trans.*, 1802.]

[Herschel (W.)]

"Sir WILLIAM HERSCHEL, from a London paper."

[This is a short obituary notice "furnished by a gentleman well acquainted with Sir WILLIAM and his family, and its accuracy may be relied on."]

Niles' Register, vol. 23, p. 154, November 9, 1822. 8vo.

[Herschel (W.)]

Obituary: Sir WILLIAM HERSCHEL, Knt., LL.D., F.R.S.

The Gentleman's Magazine and Historical Chronicle, vol. xcii, 1822, p. 274. 8vo.

[Herschel (W.)]

Annual Register, 1822, p. 289. 8vo.

[Herschel (W.)]

W. HERSCHEL'S Sämmtliche Schriften. Erster Band. Ueber den Bau des Himmels. Mit 10 Kupfertafeln. [Edited by J. W. PFAFF. A second edition was published in 1850.] Dresden and Leipzig, 1828. 8vo.

[Herschel (W.)]

New York Mirror, vol. vi, 1829–'30, p. 388.

[Herschel (W.)]

Living Age, vol. ii, p. 125, (1844). 8vo. [Reprinted from *Chambers' Journal.*]

[Herschel (W.)]

Foreign Quarterly Review, vol. 31, p. 438. 8vo.

[Review of ARAGO'S "Analyse de la Vie et des Travaux de Sir WILLIAM HERSCHEL."]

[Herschel (W.)]

ARAGO'S Life of HERSCHEL.

Eclectic Museum, vol ii, p. 556. [Reprinted from the *Foreign Quarterly Review*, vol. 31.]

Holden (E. S.)

On the inner satellites of *Uranus*. [Reduction of Sir WILLIAM HERSCHEL'S observations.]

Proceedings Amer. Assn. Adv. Science, August, 1874, p. 49. 8vo.

Holden (E. S.)

Index Catalogue of Books and Memoirs relative to nebulæ, clusters, etc. *Smithsonian Miscellaneous Collections*, No. 311, pp. 19–38. [Abstracts of Sir WILLIAM HERSCHEL'S memoirs (on nebulæ) in the *Philosophical Transactions.*]

Washington, 1877. 8vo.

Holden (E. S.)

Sir WILLIAM HERSCHEL, his life and works. New York, 1881. 12 mo. (with a portrait.)

Krafft (J. G. F.)

Kurze Nachricht von dem berühmten Astronomen HERSCHEL und einigen seiner Entdeckungen.

Bayreuth, 1787. 8vo.

Peirce (C. S.)

Photometric Researches. [A reduction of HERSCHEL'S observations on the comparative brightness of the stars.] *Annals Harvard College Observatory*, vol. ix.

Leipzig, 1878. 4to.

Sommer (G. M.)

WILLIAM HERSCHEL * * * ueber den Bau des Himmels; drei abhandlungen aus dem englischen nebersetzt, nebst einem authentischen Auszug aus KANTS allgemeiner Naturgeschichte und Theorie des Himmels.

Königsberg, 1791. 8vo.

Struve (W.)

Études d'astronomie stellaire. Sur la voie lactée et sur la distance des étoiles fixes. [P. 24 *et seq.* contains an elaborate review of the construction of the heavens according to HERSCHEL.] St. Petersburg, 1847. 8vo.

Wolf (R,)

WILLIAM HERSCHEL. Zurich, 1867. 8vo.

Zach (F. von.)

Dr. WILLIAM HERSCHEL [translated from *Public Characters* and printed in ZACH'S *Monatlich Correspondenz*, 1802, part I, p. 70, *et seq.*]

IV.—LIST OF THE PUBLISHED PORTRAITS OF WILLIAM HERSCHEL.

Artist, MME. DUPIERY. *Engraver,* THÖNERT. 8vo. Early portrait. Some copies in red. Profile.

Artist, F. REHBURG. *Engraver,* F. W. BOLLINGER. 8vo. Late portrait.

Artist, ——? *Engraver,* C. WESTERMAYR. 8vo. Medallion.

Artist, C. BRAND. *Engraver,* ——? 8vo. Lithograph.

Artist, ——? *Engraver,* J. SEWELL. 8vo. Profile, 1785.

Artist, ——? *Engraver,* ——? 8vo. Profile.

Artist, F. BONNEVILLE. *Engraver,* F. BONNEVILLE. 8vo. Profile.

Artist, J. RUSSELL, R. A. *Engraver,* E. SCRIVEN. 8vo. Engraved from a crayon in the possession of his son, and published by the S. D. U. K. in the *Gallery of Portraits,* vol. 5.

Artist, ——? *Engraver,* ——? 8vo. *European Magazine,* Jan., 1785. This is a bust in profile showing the left side of the face.

Artist, ——? *Engraver,* THOMSON. 8vo. Published by Caxton, 1823. This must have been engraved before 1816, since the legend is WILLIAM HERSCHEL, LL. D., F. R. S.

Artist, Lady GORDON. From the painting by ABBOTT in the National Portrait Gallery. *Engraver,* JOSEPH BROWN. 8vo. Published in memoir of CAROLINE HERSCHEL. This is of the date 1788, or thereabouts.

Artist, ——? *Engraver,* C. MÜLLER. 4to. Medallion. 1785 (?

Artist, ——? *Engraver,* H. PINHAS. 4to. Legend in Russian.

Artist, BAISCH. *Engraver,* ——? 4to. Lithograph.

Artist, H. GRÉVEDON. *Engraver,* ——? Fol. Lithograph.

Artist, ——? *Engraver,* F. MÜLLER. Fol.

Artist, ABBOTT. *Engraver,* RYDER. Fol. 1788.

Artist, J. BOILLY. *Engraver,* ——? Fol. 1822. Lithograph.

Artist, ——? *Engraver,* J. GODBY. Fol.

R. W. S. LUTWIDGE, Esq., F. R. A. S., has an original seal with a head of Sir WILLIAM HERSCHEL, which is shown on the title-page of this work. A cut of it has been courteously furnished me by JOHN BROWNING, Esq., F. R. A. S., etc.

In 1787 a bust of HERSCHEL was made by LOCKIE for Sir WILLIAM WATSON.

A picture of HERSCHEL was painted by Mr. ARTAUD about the beginning of 1819. A portrait of HERSCHEL by ABBOTT is in the National Portrait Gallery, London. There are no doubt many other paintings in England, though I can find notices of these only. The Royal Society of London has nearly a hundred portraits of its most distinguished members, but owns none of Sir WILLIAM HERSCHEL.

V.—SYNOPSIS OF THE SCIENTIFIC WRITINGS OF WILLIAM HERSCHEL.

Abstracts of William Herschel's Memoirs in the Philosophical Transactions of the Royal Society of London.

A.D.	*Vol.*	*P.*	
1780	70	338	*Astronomical observations on the Periodical Star in Collo Ceti.* By Mr. WILLIAM HERSCHEL, of Bath, communicated by Dr. WATSON, jr., of Bath, F. R. S. Read May 11, 1780.
		338	This star is *o Ceti,* and was first observed by DAVID FABRICIUS, August 13, 1596.
		338	HERSCHEL's observations begin 1777, October 20.
		339	β *Ceti* is brighter than α, which indicates a change since BAYER.
		340	2′ (of arc) "is hardly sufficiently large to distinguish a square from a circle."
		341	"The periodical star preceded a very obscure telescopic star" 1′ 45″ 35.

Herschel, W.: SYNOPSIS OF THE WRITINGS OF—Continued.

A.D.	Vol.	P.	
1780	70	341	This measure repeated 1′ 50″.47.
		342	This measure repeated 1′ 53″.437.
		342	This measure repeated 1′ 50″.625.
		342	This measure repeated 1′ 45″.937.
		343	"MAUPERTUIS accounts for the periodical appearances of changeable stars by supposing that they may be of a flat form, like Saturn's ring, which becomes invisible when the edge is presented to us."
		343	This star "appeared always full and round when I viewed it with a telescope"; this is not necessarily opposed to MAUPERTUIS' explanation on account of the aberrations.
		344	"KEILL says 'it is probable that the greatest part of this star is covered with spots and dark bodies, some part thereof remaining lucid; and while it turns about its axis, does sometimes shew its bright part, sometimes it turns its dark side to us, etc.'"
1780	70	507	*Astronomical Observations relating to the mountains of the Moon.* By Mr. HERSCHEL, of Bath. Communicated by Dr. WATSON, jun., of Bath, F. R. S. Read May 11, 1780.
		508	The method used by HEVELIUS and others to find the height of a mountain in the Moon explained. Figure 1.
		509–512	Quotations from GALILEO, HEVELIUS, LALANDE, FERGUSON, and KEILL.
		512	Explanation of the method used by HERSCHEL.
		513	The instrument used was a Newtonian reflector 6 feet 8 inches focal length, (usual), magnifying power 222 diameters, the aperture used was four inches. "I believe that for distinctness of vision this instrument is perhaps equal to any that was ever made."
		514	Observations in detail from November 30, 1779, to February 19, 1780.
		517	"From these observations I believe it is evident that the height of the lunar mountains in general is greatly overrated; and that when we have excepted a few, the generality do not exceed half a mile in their perpendicular elevation."
		518	"One caution, I would beg leave to mention to those who may use the excellent 3½ feet refractors of Mr. DOLLOND. The admirable quantity of light, which on most occasions is so desirable, will probably give the measure of the projection somewhat larger than the true, if not guarded against by proper limitations placed before the object-glass."
		519	Continuation of the same observations 1780, March 11—March 16.
		522	Additional memoranda of the manner in which Mr. HERSCHEL made his observations taken from a letter of his to the Astronomer Royal.
			Plate XI contains five figures (diagrams) to illustrate the methods of observation.
1781	71	115	*Astronomical Observations on the rotation of the planets round their axes, made with a view to determine whether the earth's diurnal motion is perfectly equable.* In a letter from MR. WILLIAM HERSCHEL, of Bath, to WILLIAM WATSON, M. D., F. R. S. Read January 11, 1781.
		115	While every one of the motions of the earth that arise from the actions of the sun, moon, and planets, etc., have been investigated by astronomers, there is one motion which has hitherto escaped the scrutiny of observers—the diurnal rotation round its axis.
		116	The reason why this has not been looked into is probably the difficulty of finding a proper standard to measure it by; since it is itself *the standard* by which we measure all the other motions.

Herschel, W.: Synopsis of the Writings of—Continued.

A. D.	*Vol.*	*P.*	
1781	71	116	We have no cause to suspect any very material periodical inequality.
		116	Aberration would forever have remained a secret to us if it had not been found out by other methods than that of time-keepers.
		117	No time-keeper will measure such equal portions of time as we require to compare the diurnal motion of the earth to.
		117	The diurnal rotation of the earth being at least tolerably equable, that of the other planets is likely to be also; and this suggested the thought of estimating the diurnal motion of one planet very exactly by that of another, making each the standard of the other.
		117	Such a test might detect a retardation occasioned by some resistance of a very subtle medium in which the heavenly bodies perhaps move, or any acceleration from some cause or other.
		117	The common account of the diurnal rotations of the planets was much too inaccurate for this critical purpose, and new observations were required.
		118	*Mars* was the most suitable planet for the purpose, as the dark spots on *Jupiter* change their places. These may be supposed to be large black congeries of vapors and clouds swimming in the atmosphere of *Jupiter*.
		118	The bright spots also, though they may adhere firmly to the body of *Jupiter*, may undergo some change of situation by being differently covered or uncovered, on one side or the other, by alterations in the belts.
		118	The same bright spot, not suspected of any change of situation, gave by one set of observations $9^h\ 51^m\ 45^s.6$, and by another set $9^h\ 50^m\ 48^s$.
		118	The analogy of the trade-winds on the earth may account for all the irregularities of *Jupiter's* revolutions deduced from spots on the disc
		119	If, with Cassini, we suppose his rotation-time to be $9^h\ 56^m$, then some spots that I have observed must have been carried through about 60° of *Jupiter's* equator in 22 of his days. This very large velocity in the clouds is not unparalleled by what has happened in our own atmosphere.
		119	The spots on *Mars* are of a different nature. Their constant and determined shape, as well as remarkable color, show them to be permanent, and fastened to the body of the planet.
		119	Suppose that we can determine whether a spot on the disc of *Mars* is or is not in the line which joins the center of the earth and the center of that planet to half an hour's time with certainty, in this case we shall in 30 days have the revolution true to a minute, and in three months to 20^s. An interval of about 780 days (the next opposition) will give the diurnal motion true to about 2^s, etc.
		120	Had such observations as these been made 2000 or 200 years ago, we might now, by repeating them, most probably become acquainted with some curious minute changes that may have hitherto passed unnoticed.
		120	The difference between the polar and equatorial diameters of the earth is by actual measurement 36.9 miles, by theory 33.8, from which it should seem probable that when the earth assumed the present form the diurnal rotation was somewhat quicker than it is at present. But I would not lay much stress upon this argument.
		121	The telescopes used were of my own construction, and are a 20-feet Newtonian reflector, a 10-feet reflector of the same form, and the 7-feet reflector already mentioned (*Phil. Trans.* 1780, p. 513).
		121	The time was determined with a brass quadrant of 2 feet radius, carrying a telescope magnifying 40 diameters.

Herschel, W.: SYNOPSIS OF THE WRITINGS OF—Continued.

A. D.	*Vol.*	*P.*	
1781	71	121	Two very good clocks were used; one having a deal pendulum rod and one a compounded one of brass and iron, both having a proper contrivance not to stop when winding up. The rate of going of my clocks I determined by the transit of stars.
		121	Observations on *Jupiter* in the year 1778. February 24—April 12. (See Plate V, Figs. 1 to 12, drawings of *Jupiter*.)
		123	Observations on *Jupiter* in 1779. April 14—April 23. See Plate V, Fig. 13 [misprinted 18].
		124	Comparing the observations two and two the following times of one synodical revolution: $9^h\ 54^m\ 56^s.4$ from an interval of 17 revolutions; $9^h\ 55^m\ 20^s$ from an interval of 12 revolutions; $9^h\ 55^m\ 24^s$ from an interval of 15 revolutions; $9^h\ 55^m\ 4^s.6$ from an interval of 41 revolutions; $9^h\ 55^m\ 40^s$ from an interval of 1 revolution; $9^h\ 54^m\ 58^s.2$ from an interval of 29 revolutions; $9^h\ 54^m\ 53^s.4$ from an interval of 26 revolutions; $9^h\ 51^m\ 35^s$ from an interval of 12 revolutions; $9^h\ 51^m\ 45^s.6$ from an interval of 12 revolutions; $9^h\ 50^m\ 48^s$ from an interval of 10 revolutions; $9^h\ 51^m\ 19^s.4$ from an interval of 22 revolutions; combining the two preceding.
		126	These several results are so various that it is evident that *Jupiter* is not a proper planet for this critical purpose. This great variety cannot proceed from inaccuracy in the observations; for, in my opinion, it is not possible to make a mistake in the position of a spot which shall amount to 5 minutes of time, as was proved by the observation of April 23, 1779.
		126	The synodical revolutions have not been reduced to sidereal ones.
		126	By a comparison of the different periods it appears that a spot gradually performs its revolutions in less time than it did at first. Examples of this are given.
		126	This is consonant with the theory of equatorial winds.
		127	Observations on *Mars* in the year 1777. (April 8—April 27.) See Plate VI, Figs. 14—19, drawings of *Mars*.
		128	Observations on *Mars* in the year 1779. (May 9—June 17.) Figs. 20—23, drawings of *Mars*.
		130	Comparing the observations of 1779 two and two the periods are: $24^h\ 38^m\ 1^s.5$ from an interval of 2 revolutions; $24^h\ 34^m\ 1^s.5$ from an interval of 2 revolutions; $24^h\ 38^m\ 5^s.9$ from an interval of 36 revolutions; $24^h\ 38^m\ 5^s.4$ from an interval of 38 revolutions; $24^h\ 38^m\ 20^s.3$ from an interval of 34 revolutions.
		131	Method of reducing synodic revolutions to sidereal (see Fig. 24, diagram).
		133	The sidereal periods from observations of 1777 and 1779 are: $24^h\ 39^m\ 23^s.03$ from an interval of 768 revolutions; $24^h\ 39^m\ 18^s.94$ from an interval of 763 revolutions; $24^h\ 39^m\ 23^s.04$ from an interval of 763 revolutions.
		134	$24^h\ 39^m\ 21^s.67$ the adopted sidereal revolution of *Mars* on his axis. [PROCTOR's value, $24^h\ 37^m\ 22^s.715$.]

Herschel, W.: SYNOPSIS OF THE WRITINGS OF—Continued.

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1781 71 134 Consideration of three sources of possible error: I, a mistake in the whole number of revolutions; II, a mistake in estimating the time when a spot comes to a certain place; III, the [determination of the] time may be in error.

135 A mistake in the whole revolutions would have made an error of 1^h in the concluded rotation time, and the agreement of the three results shows that no such mistake has been made.

The second cause of error is of some force. An error of 10^m is not likely, as is shown by the results of some experiments. These were made by placing dots within circles drawn on paper, the (eccentric) positions of the dots corresponding to positions of a spot on *Mars*, 10, 15, and 20 minutes distant from his centre. These were shown to various persons, who all agreed in locating the dots on the proper side of the centre.

136 The time was satisfactorily determined in 1779, but in 1777 not so much so, as I was then not provided with an altitude instrument.

136 Allowing for this, the uncertainty of the deduced rotation period is estimated at not above $2^s.34$.

137 An ephemeris of the times of appearances of a dark spot on *Mars* has been calculated for 1781 [and is given, p. 138].

138 Observation of the beginning and ending of the *solar eclipse* of June 24, 1778.

1781 71 492 *Account of a Comet.* [The planet *Uranus.*] By Mr. HERSCHEL, F. R. S., communicated by Dr. WATSON, jun., of Bath, F. R. S. Read April 26, 1781.

492 "On Tuesday, March 13 [1781], between 10 and 11 in the evening, while I was examining the small stars in the neighborhood of *H Geminorum*, I perceived one that appeared visibly larger than the rest. Being struck with its uncommon magnitude, I compared it to *H Geminorum* and the small star in the quartile between *Auriga* and *Gemini*, and finding it so much larger than either of them, suspected it to be a comet."

492 The magnifying power used "when I first saw the comet was 227." By applying higher powers (460 and 932) the diameter of the comet increased in proportion to the power, while the diameters of the stars to which I compared it were not increased in the same ratio.

494 Measures of the comet's diameter (March 17, April 18); the measures vary from 3″ 53‴ to 5″ 20‴.

494 "By experience I have found that the aberration or indistinctness occasioned by magnifying much, provided the object be still left sufficiently distinct, is rather to be put up with than the power to be reduced when the angles to be measured are extremely small."

496 Distance of the comet from certain telescopic stars. [See diagrams of these stars and the comet in Plate XXIV, 1–6.]

497 Position-angles.

498 Miscellaneous observations and remarks.

March 19: It moves according to the order of the signs, and its orbit declines but very little from the ecliptic.

April 6: The comet appeared perfectly sharp at the edges and extremely well defined.

498 Remarks on the path of the comet.

499 The field of view was bright, the micrometer-thread black.

Herschel, W.: SYNOPSIS OF THE WRITINGS OF—Continued.

A. D.	Vol.	P.	
1781	71	500	Description of a Micrometer for taking the angle of position. (See PLATE XXVI, figs. 1, 2, 3, 4.) This is the modern form.
1782	72	82	*On the Parallax of the Fixed Stars*, by Mr. HERSCHEL, F. R. S.; communicated by Sir JOSEPH BANKS, Bart., P. R. S. Read December 6, 1781.
		82	The nearest of the fixed stars cannot be less than 40,000 diameters of the whole annual orbit of the earth distant from us.
		82	As we cannot enlarge this base, we can only endeavor to improve the instruments by which we measure the parallax.
		82	To measure small angles with accuracy two things are necessary: 1st, that the instrument used for the purpose should be divided with sufficient exactness; and 2d, that the telescope should have an adequate power and distinctness.
		83	The first condition is (now) practically fulfilled. The chief difficulty is in the optical part. To see 1″ with precision requires a telescope of very great perfection.
		83	Even supposing the parallaxes of stars not to amount to single seconds, or even thirds [$\frac{1}{60}''$], the observations necessary to show this would still have value.
		84	The next step necessary to consider in this undertaking was the manner of putting it into execution.
		84	The method proposed by GALILEO, and attempted by HOOK, FLAMSTEED, MOLINEUX, and BRADLEY, of measuring zenith distances of stars which pass close to the zenith, though it failed with regard to parallax, has been productive of the most noble discoveries of another nature.
		84	BRADLEY (in *Phil. Trans.*, No. 406, p. 637) concludes that the parallax of γ *Draconis*, or of η *Ursæ Majoris*, "is not so great as one single second."
		85	γ *Draconis* is a bright third magnitude, and the conclusion that several authors have reached, that the parallaxes of stars in general do not exceed 1″, does not appear to me to follow from the observations. For aught we know to the contrary, the stars of the first magnitude may still have a parallax of several seconds.
		86	The method of zenith distances labors under the following considerable difficulties: In the first place, the refractions; 2d, the change of position of the earth's axis, arising from nutation, precession, and other causes, is not completely settled; 3d, the aberration, though best known of all, may also be liable to some small errors.
		87	I shall now deliver the method I have taken and show that it is free from every error to which the former is liable, and is still capable of every improvement the telescope and mechanism of micrometers can furnish.
		87	Let O and E (fig. 1) be two opposite points of the earth's orbit, in the same plane with two stars, *a* and *b*, of unequal magnitude. Let the angle *a*O*b* be observed when the earth is at O, and *a*E*b* when the earth is at E. From the difference of these angles we may calculate the parallax of the stars. These two stars ought to be as near each other as possible, and also differ as much in magnitude as we can find them.

Herschel, W.: SYNOPSIS OF THE WRITINGS OF—Continued.

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1782 72 88 GALILEO was the first who suggested this method; but he does not observe that the stars should be so near to each other as thereby to preclude the influence of every cause of error.

88 This method has been also mentioned by other authors. Dr. LONG observed γ *Arietis*, α *Geminorum*, θ *Orionis*, and γ *Virginis*, and "was persuaded that they would be found always to remain the same."

88 Every one of these stars are [*sic*] totally improper for the purpose; for the stars in γ *Arietis* are near 10″ distant, and, moreover, equal in magnitude. In α *Geminorum* the stars are near enough, but do not sufficiently differ in magnitude to shew any parallax. The stars in the Nebula of *Orion*, on account of their extreme smallness of distance, are still more improper than any; and those of γ *Virginis* are equal in magnitude.

88 The magnifying powers used by GALILEO and LONG were too small, not above 60 or 70.

89 From a great number of observations which I have already made on several double stars, especially ε *Boötis*, it appears that we can affirm the annual parallax to be exceedingly small indeed; and that there is a great probability of succeeding still farther in this laborious but delightful research, so as to be able at last to say, not only how much the annual parallax *is not* but how much it really *is*.

90 Discussion of the effect of refraction on such measures.

91 Too much has hitherto been taken for granted in optics. Why the method (of experiment) should not be more pursued in the art of seeing does not appear.

92 We are told that we gain nothing by magnifying *too much*. I grant it; but shall never believe I magnify too much till by experience I find that I can see better with a lower power.

92 Telescopes will in general discover more small stars the more light they collect, yet with a power of 227 I cannot see the small star following *o Aquilæ*, when by the same telescope it appears very plainly with the power of 460. Now in the latter case the light is less than the fourth part of the former.

93 Other similar cases noted and the names of the small stars given.

93 Great power may be favorable in cases where two stars are close together. Figs. 2–5 show α *Lyræ* with powers 460, 2,010, 3,168, and 6,450 with my Newtonian reflector.

94 A new micrometer has been invented, which will be described in a subsequent paper.

94 The powers that may be used upon various double stars are different according to their relative magnitudes; ε *Boötis*, for example, will not bear the same power as α *Geminorum*.

95 I have always found a single eye-glass had much the superiority over a double eye-glass, both in light and distinctness. I would except those cases where a large field is necessary.

95 If we would distinctly perceive and measure extremely small quantities, such as a tenth of a second, it appears that when we use a power of 460 this tenth of a second will be no more in appearance than 46″, and even with a power of 1,500 will be but 2′ 30″, which is a quantity not much more than sufficient to judge well of objects and to distinguish them from each other, such as a circle from a square, triangle, or polygon.

Herschel, W.: SYNOPSIS OF THE WRITINGS OF—Continued.

A. D.	*Vol.*	*P.*	
1782	72	96	[Foot-note.] By a set of experiments made in 1774 I found that I could discover or perceive a bright object, such as white paper, against the skylight when it subtended an angle of 35″, but could only distinguish it to be a circle, and no other figure, when it appeared under an angle of 2′ 24″.
		96	We must look for distinctness in the perfection of the object speculum of a telescope, and if we can make the first image in the focus of a speculum almost as perfect as the real object, what should hinder our magnifying but loss of light?
		96	The stars having light sufficient, I see no reason why we should limit the powers of our instruments by any theory.
		97	In this research it became necessary to look out for proper stars. I took some pains to find out what double stars had been recorded by astronomers, but my situation permitted me not to consult extensive libraries. Nor indeed was it very material; for, as I intended to view the heavens myself, Nature, that great volume appeared to me to contain the best catalogue upon this occasion.
		97–8	Enumeration of a few double stars which were known when this research began.
		98	If I should mention any observations that are difficult to be verified I beg the indulgence of observers. I hope it will be found that I have sufficiently guarded against optical illusions, and that I have all along had truth and reality in view as the sole object of my endeavors.
		99	In the observations of the *distances* of double stars, I have used two ways. Those which are extremely near to each other may be estimated by the eye in measures of their own apparent diameters. Such estimations are accurate, as is shown by experiments with circles drawn on paper near together.
		100	I have divided double stars into several classes. Class I contains the most difficult.
		100	These being the most delicate objects it will not be amiss to go gradually through a few preparatory steps of vision.
		100	Examples of such preparatory steps given.
		101	These double stars are a most excellent way of trying a telescope.
		101	Class II of double stars contains all those that are proper for estimations by the eye, or very delicate measures of the micrometer. See fig. 6 of *α Geminorum*.
		102	Estimations made with one telescope cannot be compared to those made with another.
		102	Whatever may be the cause of the apparent diameters of the stars, they are certainly not of equal magnitude with the same powers in different telescopes, nor of proportional magnitude with different powers of the same telescope.
		102	Class III contains all double stars more than 5″ and less than 15″ asunder.
		103	Class IV contains double stars 15″ to 30″ asunder. Class V contains double stars 30″ to 60″ asunder. Class VI contains double stars 60″ and over asunder.
		103	These may serve another very important end. I will just mention it, though it is foreign to my present purpose. Several stars of the first magnitude have been observed or suspected to have a proper motion of their own; hence we may surmise that our sun, with

Herschel, W.: SYNOPSIS OF THE WRITINGS OF—Continued.

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all its planets and comets, may also have a motion toward some particular point of the heavens. If this surmise should have any foundation it will show itself in a series of some years in a kind of systematical parallax or change due to the motion of the whole solar system.

1782 72 104 Theory of the annual parallax of double stars; General Postulata:
1. Let the stars be supposed, one with another, to be about the size of the sun.

104 2. Let the difference of their apparent magnitudes be owing to their different distances, so that a star of the 2d, 3d, 4th magnitude is 2, 3, 4 times as far off as one of the first.

104 [Foot-note.] This is rather the order into which stars ought to be divided than that into which they are. And perhaps we ought to make an allowance for some loss which may happen to the light of very remote stars in its passage through immense tracts of space most probably not quite destitute of some very subtle medium.
I have usually found very small telescopic stars to be red, or inclined to red.

105 Case of the parallax of stars in the ecliptic.

106 The following general expression for the parallax of two stars:
Let P express the total parallax of a fixed star of the first magnitude; M the magnitude of the largest of the two stars; m the magnitude of the smallest, and p the partial parallax to be observed by the change in the distance of a double star; then will $p = \frac{m-M}{Mm}$. P and p being found by observation will give us $P = \frac{pMm}{m-M}$.

107 Cases where the stars are not in the ecliptic.

1782 72 112 *Catalogue of Double Stars.* By Mr. HERSCHEL, F. R. S., communicated by *Dr.* WATSON, jun. Read January 10, 1782.

112 Introductory remarks. The catalogue contains, I. The names of the stars, etc. II. Their comparative size. III. Their colors. IV. Their distances, which are given several different ways. Those estimated by the diameter can hardly be liable to an error of so much as 0″.25. Those measured by the micrometer may have errors from 1″ to 2″. A new micrometer [Lamp-Micrometer, P. T., 1782, p. 163], made within a few months, gives measures which can be relied on to 0″.1 when a mean of three measures is taken. V. The angles of position; when measured they can be relied on to 2° or 3°. VI. The dates of discovery.

115 Catalogue of Double Stars; First Class [24 stars].

120 *h* Draconis: "It is in vain to look for them if every circumstance is not favorable. The observer as well as the instrument must have been long enough out in the open air to acquire the same temperature. In very cold weather an hour at least will be required; but in a moderate temperature half an hour will be sufficient."

122 Second Class of Double Stars [38 stars].

128 *ζ Sagittæ:* the small star brighter with 460 than with 227 or 278.

129 Third Class of Double Stars [46 stars].

131 *γ Delphini:* "I suspect a motion in one of these stars. I thought it best not to join other observations" to those of 1779.

136 Fourth Class of Double Stars [44 stars].

142 Fifth Class of Double Stars [51 stars].

Herschel, W.: SYNOPSIS OF THE WRITINGS OF—Continued.

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1782 72 143 *ι Boötis:* "I suspect a motion in one of the stars, which another year or two may show."

143 *ν Draconis:* "From the position in FLAMSTEED'S catalogue" we gather that in his time their distance was * * * *. The difference in the distance of the stars is so considerable that we can hardly account for it otherwise than by admitting a proper motion in one or both of the stars or in our solar system; most probably neither of the three is at rest."

147 *α Lyrae:* I have often measured the diameters of the fixed stars, and found they measured less and less the more I magnified. With a power of 6450 I looked at this star for at least a quarter of an hour, * * * having experimentally found that the aberration by this means will appear less and less. *α Lyræ* was perfectly round; its diameter was 0″.3553.

150 Sixth Class of Double Stars [66 stars].

150 *o Ceti:* "I can hardly doubt the motion of this star."

157 Postscript to the Catalogue of Double Stars.

Since delivering the paper on the Parallax of the Fixed Stars [*Phil. Trans.*, 1782], in which I refer to the above Catalogue of Double Stars, I have received a paper of Mr. MAYER'S "De novis in Cœlo sidereo phænomenis" wherein I see that the idea of ascertaining the proper motion of the stars by means of small stars near large ones has induced that gentleman before me to look out for such small stars. My view being that the annual parallax required stars much nearer than

158 those that would do for Mr. MAYER'S purpose, therefore I examined the heavens with much higher powers, and looked out chiefly for those that were exceedingly close. The above catalogue contains 269 double stars, 227 of which, to my present knowledge, have not been noticed by any person. I hope they will prove no inconsiderable addition to the general stock, especially as there are a great many which are out of the reach of Mr. MAYER'S and other mural quadrants or transit instruments.

158 A power of 70 or 80 was not enough for the stars of Class I nor even those of Class II.

158 In settling the relative situation of very close double stars neither Mr. MAYER'S instrument nor his method were adequate to the purpose.

159 Comparison of the measures of MAYER and HERSCHEL on *α Geminorum:*

"Mr. MAYER: Distance, 9″.635 from center to center; position, 23° 14′ n. preceding; magnitude, extremely unequal. Mine: Distance, 5″.156, diameter included; position, 32° 47′ n. preceding; magnitudes, a little unequal." [See Fig. 6, Plate IV, for a cut of the appearance of this star with power of 460.]

160 I do not mean to depreciate Mr. MAYER'S method; with stars of Classes IV, V, VI, and some of Class III, better can hardly be wished for; it is not sufficient for stars of Class II, much less for those of Class I.

161 I have used the expression "double star" in a few instances of Class VI in rather an extended signification. I preferred that expression to any other such as comes, companion or satellite, because, in my opinion, it is much too soon to form any theories of small stars revolving round large ones.

162 I shall not fail to take the first opportunity for looking out for those of Mr. MAYER'S double stars which I have not in my catalogue, amounting to 31, and also for [another in Connaissance des Tems].

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1782 72 163 *Description of a Lamp Micrometer, and the method of using it.* By Mr. WILLIAM HERSCHEL, F. R. S. Read January 31, 1782.

163 The imperfections of the parallel wire micrometer in taking the measures of close double stars are [described]: 1st, that the measures must include the diamters of the stars; 2d, the deflection of the light on the wires [single threads of the silk-worm were used]; 3d, the uncertainty of the zero; 4th, the imperfection of the screw; 5th, the necessary illumination of the field.

164 The *Lamp-Micrometer* is free from all these defects. Description and reference to Plate V.

169 The powers of HERSCHEL's telescopes were [at this time] determined by looking at a scale with one eye free and the other at the instrument.

169 Description of the method of observing.

170 "A little practice in this business soon makes it easy, especially to one who has already been used to look with both eyes open."

Example of the measure of the position of α *Herculis*.

("My telescope bears a power of 460 so well that for a twelvemonth past I have hardly used any other.")

171 "A power of 932 on fine evenings is very distinct," and gives more than half an inch to a second on the Lamp-Micrometer.

171 Other applications of this micrometer are to the measures of the diameters of the planets and satellites, the mountains of the moon, the diameters of the fixed stars, etc.

171 Example of the measure of the diameter of α *Lyræ* [diameter 0''.355].

171 Nov. 28, 1781. I measured the diameter of the new star [*Uranus*]. The diameter of this "singular star" was 5''.022.

1782 72 173 *A paper to obviate some doubts concerning the great magnifying powers used.* By Mr. HERSCHEL, F. R. S.

[In the form of a letter to Sir JOSEPH BANKS, Prest. R. S.]

173 I have the honor of laying before you the result of a set of measures I have taken to ascertain once more the powers of my Newtonian 7-feet reflector.

174 The method described. The solar focus of one of the eye-pieces was measured five times and found to be 1.01, 1.04, 1.09, 1.01, 1.05 in half-inch measure. The sidereal focus of my 7-feet speculum in the same measure is 170.4. The mag. power of that lens is, then, 163.8. This eye-lens was then compared with others by measures of the diameter of a brass wire [details of the experiment given].

175 Powers as they have been called in my papers, 146, 227, 278, 460, 754, 932, 1159, 1536 [this lens lost 8 months ago], 2010, 3168, 6450.

Powers as they come out by this method, 163.86, 250.7, 301.8, 496.7, 775.1, 986.7, 1179.9, ——, 2175.8, 2585.5, 5786.8.

175 Description of the method formerly used to determine these powers: In 1776 a mark of white paper exactly half an inch in diameter was viewed at the greatest convenient distance with the least magnifiers. An assistant was placed at rectangles in a field at the same distance, and upon a pole there erected I viewed the magnified image of the half inch which was marked by my direction. The power thus obtained was corrected to reduce it to what it would be upon infinitely

176 distant objects. The powers of the rest of the lenses I deduced from this by a camera eye-piece. [See Plate VI, figs. 1 and 2.]

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A. D.	*Vol.*	*P.*	
1782	72	176	The inconvenience of the first method is that we find out how much the telescope *should* magnify rather than how much it really *does* magnify.
		177	To prevent any mistakes I wish to mention again that I have all along proceeded experimentally in the use of my powers, and that I do not mean to say I have used 6450 (or 5786) upon the planets, or even upon double stars. The use of high powers is a new and untrodden path, and in this attempt variety of new phænomena may be expected, therefore I wish not to be in a haste to make general conclusions. I shall not fail to pursue this subject, and hope soon to be able to attack the celestial bodies with a still stronger armament which is now preparing.
1783	73	1	*A letter from William Herschel, esq., F. R. S.*, to Sir JOSEPH BANKS, Bart., P. R. S.
		1	The name *Georgium Sidus* proposed for the new star discovered in March, 1781. [*Uranus.*]
1783	73	4	*On the Diameter and Magnitude of the Georgium Sidus; with a description of the dark and lucid disk and periphery micrometers.* By WILLIAM HERSCHEL, Esqr., F. R. S. Read November 7, 1782.
		5	The measures of the diameter of the *Georgium Sidus* formerly communicated give 4″ 36½‴. But not being satisfied, when I thought it possible to obtain much more accurate measures, I employed the lamp micrometer.
		5	A lucid disk and not two lucid points was really required, and the following apparatus was contrived. [Description follows.] The
		6	planet was kept by a good screw opposite and covering illuminated oiled paper disks, and the sizes of these measured.
		7	Observations on the Light, Diameter, and Magnitude of the *Georgium Sidus*. [From Oct. 22, 1781, to Nov. 4, 1782.]
		7	Oct. 22, 1781, "had a fine, bright, steady light, of the color of *Jupiter*, or approaching to the light of the moon."
		8	Oct. 2, 1782. "The planet unexpectedly appeared bluish," while the oiled disk was reddish.
		9	Oct. 10, 1782, determined the magnifying power of the telescope again in a new way [described].
		11	There is one cause of inaccuracy or deception in very small [close] measures, long suspected but never yet sufficiently investigated. A *dispersion* of the rays of light in the atmosphere may be admitted; a *concentration* may also take place.
		11	Oct. 12, 1782. The planet visible to the naked eye.
		11	Oct. 13, 1782. "I perceived no flattening of the polar regions."
		12	Nov. 4, 1782. "I was now fully convinced that light, be it in the form of a lucid circle or illuminated periphery, would always occasion the measures to be less than they should be, on account of its vivid impression upon the eye" [and a dark circle in a bright square was used for comparison].
		12	A method to discover the quantity of the deception arising from the illumination pointed out.
		13	The diameter of the *Georgium Sidus* cannot well be much less, nor perhaps much larger, than about 4″.

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1783 73 247 *On the proper motion of the Sun and Solar System; with an account of several changes that have happened among the fixed stars since the time of* Mr. FLAMSTEED. By WILLIAM HERSCHEL, Esq., F. R. S.
Read March 6, 1783.

247 Several of the fixed stars have a proper motion.

248 We may strongly suspect that there is not, in strictness of speaking, one *fixed* star in the heavens, and reasons which I shall adduce will render this so obvious that there can hardly remain a doubt of the general motion of all the starry systems, and, consequently, of the solar one among the rest.

248 Reasons drawn from the theory of attraction evidently oppose every idea of absolute rest in any one of the stars, when once it is known that some of them are in motion.

249 I will give a general account of the most striking changes which I have found to have happened in the heavens since FLAMSTEED'S time. I have now almost finished my third review.

249 The first review was made with a Newtonian telescope something less than 7 feet focal length, a power of 222, and an aperture of 4½ inches. It extended only to stars of the first, second, third, and fourth magnitudes.

249 Of my second review I have given some account in *Phil. Trans.*, vols. LXX, LXXI, LXXII. It was made with an instrument much superior to the other of 85.2 inches focus, 6.2 inches aperture, and power 227. It extended to all the stars of HARRIS'S maps, and the telescopic ones near them as far as the eighth magnitude. The Catalogue of Double Stars and the discovery of the *Georgium Sidus* were the results of that review.

My third review was with the same instrument and aperture, but
250 with a power of 460. This extended to all the stars of FLAMSTEED'S catalogue, together with every small star about them, to the amount of a great many thousands of stars.

250 It may be proper to mention that I have many a night, in the course of 11 or 12 hours of observation, carefully and singly examined not less than 400 celestial objects, besides taking measures, and sometimes viewing a particular star for half an hour together, with all the various powers.

250 The particularities attended to in this [third] review were—

1. The existence of the star itself, such as it is given by FLAMSTEED.
2. To observe well whether it was single or double, well defined or hazy.
3. To view and mark down its particular color.
4. To examine all the small stars in the neighborhood as far, at least, as the twelfth magnitude.

The results of these observations I shall collect under a few general heads, as follows:

250 I. Stars that are lost or have undergone some capital change since FLAMSTEED'S time.

254 II. Stars that have changed their magnitude since FLAMSTEED'S time.

257 III. Stars newly come to be visible.
[Several red and garnet stars in this list.]

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1783 73 258 Here we ought to observe that it is not easy to prove a star to be newly come.

259 "Does it not seem natural that these observations should cause a strong suspicion that most probably every star in the heavens is more or less in motion?" For though their proper motions could not cause all these changes, yet we may well suppose that motion is in some way concerned.

259 A slow motion, for instance, in an orbit round some opaque body might account for some of these changes, while others might be owing to the periodical return of large spots, which become visible by a rotation. The idea also of a body flattened by a quick rotation and having a motion whereby more of the luminous surface would be exposed at one time than another tends to the same end.

260 If the proper motion of the stars be admitted, who can deny that of our sun? Admitting this for granted, the greatest difficulty will be to discern the proper motion of the sun between so many other motions of the stars. This is an arduous task indeed, but we are not to be discouraged in the attempt. Let us at all events endeavor to lay a good foundation for those who are to come after us. I shall therefore now point out the method of detecting the direction and quantity of the supposed proper motion of the sun, and show that we have already some reasons to guess which way the solar system is probably tending its course. [See Figs. 1 and 2.]

261 From the explanation of the figures it follows that—

1. The greatest or total systematical parallax of the fixed stars will fall upon those that are in the line DE at rectangles to the direction AB of the sun's motion.
2. The partial systematical parallax of every other star [defined in amount].
3. The parallax of stars at different distances will be inversely as those distances.
4. Every star at rest, to a system in motion. will appear to move in a direction contrary to that in which the system is moving.

Hence it follows that if the sun be carried toward any star in the ecliptic, every star in [one half of the ecliptic] will decrease in longitude, and every star in [the other half] will increase.

262 No method is so proper for this purpose as to divide our observations into 3 zones, viz: the equator and the two colures, and double stars are the most suitable for the purpose. Each of the 3 zones [contains double stars, which are in the previous list].

263 The equatorial zone, 20° wide, contains 150 stars. [List of them given.]

264 The zone of the equinoctial where 20° wide contains 70 double stars. [List given.]

265 The zone of the solstitial where 20° wide contains 120 double stars. [List given.]

266 A zone 20° wide of the ecliptic of 120 double stars may be added. [List given.]

266 It remains now only for me to make an application of this theory to some of the facts we already know.

267 And first let me observe that the rules of philosophizing direct us to refer all phenomena to as few and simple principles as are sufficient *to explain* them. [An example given.]

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1783 73 267 Dr MASKELYNE's proper motions of seven of the stars quoted, and the positions of these stars plotted on Fig. 3.

268 The motion of the sun towards the constellation of *Hercules* from a point not far from the 77th degree of right ascension to its opposite 257th degree will account for the proper motions of these stars by the single motion of the Solar System.

269 LALANDE gives the proper motion of 12 stars [table], and Fig. 4 rep-
270 resents them projected on the plane of the equator. These stars with others [named] give us 27 motions to be accounted for. Our supposition of the sun's motion accounts for 22 of these, so there
271 are but 5 exceptions, which must be resolved into the real proper motions of the stars.

272 The apparent exception of *Castor* considered [and the physical connection of the two components is not assumed].

273 The apex of the solar motion defined.

273 As to the quantity of the solar motion I can only offer a few distant hints.

274 The solar motion can certainly not be less than that which the earth has in her annual orbit.

274 Future observations will soon throw more light on this interesting subject, and either fully establish or overthrow the hypothesis. To this end I have already begun a series of observation upon several zones of double stars, and should the result of them be against these conjectures I shall be the first to point out their fallacy. [Dated at Datchet, near Windsor, Feb. 1, 1783.]

274 *Postscript to the paper on the Motion of the Solar System.*
Mr. AUBERT has furnished me with TOB. MAYER's *Opera Inedita*, which contains a catalogue of 80 stars observed by MAYER in 1756, compared with ROEMER's observations of 1706.

275 I have used these stars and left out of the list all those whose proper motions MAYER considers doubtful and the fourteen stars already examined, and which have been shown to support the hypothesis. The rest are drawn up in two tables. The first contains the stars that agree with my assigned motion of the solar system. The second contains those stars whose motions cannot be accounted for on my hypothesis, and must therefore be ascribed to a real motion in the stars themselves or to some *still more hidden* cause of a *still remoter* parallax.

[This phrase is explained by a foot-note, as follows:]

276 [Foot-note.] Mr. MICHELL's admirable idea of the stars being collected into systems appears to be extremely well founded; though it does not, in my opinion, take away the probability of many stars being still, as it were, *solitary* or *intersystematical*. Hence there may be a proper motion of the whole system to which a star belongs. Examples given of an inhabitant of *Saturn's* fifth satellite; or a small nebula may consist of many stars and have a proper motion as a system.

277 [Foot-note.] We see, then, that while the sun is going toward a certain point of the heavens each of the stars belonging to the sidereal system, of which the sun is one, will be affected as I have shown [p. 261] notwithstanding the whole system should have a real motion in absolute space, and change its position with respect to other systems or intersystematical stars.

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1783 73 277 [Foot-note.] And should there ever be found, in any particular part of the heavens, a concurrence of proper motions of quite a different direction we shall then perhaps begin to form some conjectures as to which stars may possibly belong to ours and which to other systems.

278 Discussion of the data of the tables.

279 The general law according to which the declinations of the stars are governed is this: Let an arc of 90° be applied to the sphere of the fixed stars so as always to pass through the apex of solar motion. Then while one end of it is drawn along the equator the other will describe a closed curve. The law is that all stars in the northern hemisphere situated within the nodated part will seem to go to the north by the motion of the solar system; the rest will appear to go southward. A similar law applies for the southern hemisphere. See Fig. 5 and Fig. 6 and the explanation, p. 280.

281 A paragraph of MAYER'S [quoted] which seems to contain an objection against the solar motion is really a good argument in its favor, as is shown. MAYER'S paper was read in 1760, and mentions the motion of the solar system as a very possible thing, and points out some of the consequences of such a motion.

283 The foot-note gives a reference to two other papers of the same sort, one by WILSON (1777), and one by LALANDE (1776).

1784 74 233 *On the remarkable appearances at the polar regions of the planet Mars, the inclination of its axis, the position of its poles, and its spheroidical figure; with a few hints relating to its real diameter and atmosphere.* By WILLIAM HERSCHEL, Esq., F. R. S. Read March 11, 1784.

234 The polar spots of *Mars* may afford a good means of "settling the inclination and nodes of that planet's axis." It was a question to be settled by observation how far these spots were permanent and in what latitude of Mars they were situated.

235 *Observations* from 1777, April 17, to 1783, Nov. 11. See Plate VI, where there are 24 drawings.

237 1783, May 20. The polar spot, which is bright, seems to project above the disk by its splendor.

238 [From observations up to 1783, Sept. 25.] I concluded that none of the bright spots were exactly at the poles, though not far from them.

241 Appearances explained by graphical constructions, Plates VII, VIII, IX, X.

243 Table giving the synodical places of the spots at the times of the different observations.

247 *Of the direction or nodes of the axis of Mars, its inclination to the ecliptic, and the angle of that planet's equator with its own orbit.*

248 Observations of angle of position of the polar spots.

252 Method of correcting the observations.

254 Table of resulting corrections.

254 From 13 observations reduced to 1783, October 4, the position of the axis of *Mars* was 55° 41′ *s. f.*

256 From 2 observations reduced to 1781, June 25, this position was 75° 11′ *s. p.*

256 The north pole of *Mars* must be directed towards some point of the heavens between 9 *s.* 24° 35′ and 0 *s.* 7° 15′.

258 *Method of* reducing the elements from the ecliptic to the orbit of *Mars*.

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1784 74 259 *Inclination* of the axis of *Mars* 61° 18′ to the orbit; the *node* being in 19° 28′ of *Pisces.*

260 The analogy between *Mars* and the earth pointed out.

260 The bright polar spots are probably owing to the vivid reflection of light from frozen regions, and the reduction [in size] of these spots is to be ascribed to their being exposed to the sun.

261 *Of the spheroidical figure of Mars.*

262 *Observations relating to the polar flattening of Mars.*

These all show a difference in the polar and equatorial diameters; even when the mirrors of the telescopes are turned 90° in their tubes, and various telescopes employed.

266 To avoid the corrections for phase, the measures taken on the day of opposition will be adopted, these having been satisfactory.

267 The equatorial diameter of *Mars* is to the polar as 1355 to 1289.

268 Corrections to this ratio considered, and the former result changed to 1355 to 1272, or as 16 to 15 nearly.

270 This difference does not depend on distortions from the eye-pieces or objectives employed.

271 The equatorial diameter of *Mars* at distance 1 is 9″ 8‴.

271 The atmosphere of *Mars.* Dr. SMITH reports an observation of CASSINI'S where a star about to be occulted by *Mars* became extremely faint 6′ from the disk of the planet.

272 Observations by HERSCHEL of faint stars near *Mars,* which show them not to be more affected than the nearness of its superior light would warrant.

273 From other phenomena it appears, however, that this planet is not without a considerable atmosphere; for besides the permanent spots on its surface I have often noticed changes in both bright and dark belts, and these alterations we can hardly ascribe to any other cause than the variable disposition of clouds and vapors floating in the atmosphere of that planet.

273 *Result of the contents of this paper:*

The axis of *Mars* is inclined to the ecliptic 59° 42′.

The node of the axis is in 17° 47′ of *Pisces.*

The point *Aries* on the Martial ecliptic answers to our 19° 28′ of *Sagittarius.*

The figure of *Mars* is that of an oblate spheroid whose equatorial diameter is to the polar one as 1355 to 1272, or as 16 to 15 nearly.

The equatorial diameter of *Mars* reduced to the mean distance of the earth from the sun is 9″ 8‴.

And that planet has a considerable but moderate atmosphere, so that its inhabitants probably enjoy a situation in many respects similar to ours.

[Dated] Datchet, Dec. 1, 1783.

1784 74 437 *Account of some observations tending to investigate the construction of the heavens.* By WILLIAM HERSCHEL, Esq., F. R. S. Read June 17, 1784.

437 A new Newtonian telescope has lately been completed, the object speculum being 20 feet in focal length and its aperture $18\frac{7}{10}$ inches.

It is mounted in the meridian and gives positions only in a coarse way.

437 It would perhaps have been more eligible to have waited longer in order to complete the discoveries that seem to lie within the reach

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of this instrument, and are already, in some respects, pointed out to me by it.

1784 74 437 By taking more time I should undoubtedly be enabled to speak more confidently of the *interior construction* of the heavens and its various *nebulous and sidereal strata*, of which this paper can give only a few hints.

438 As an apology for this prematurity it may be said that the end of all discoveries being communication, we can never be too ready in giving facts and observations, whatever we may be, in reasoning upon them.

438 Hitherto the sidereal heavens have been represented by the concave surface of a sphere. In future we shall look upon those regions into which we may now penetrate as a naturalist regards a rich extent of ground containing strata variously inclined and directed as well as consisting of very different materials.

438 Resolution of the milky way.

439 Number of stars visible in field of the 20-foot telescope.

440 Examination of MESSIER's nebulæ.

442–446 New nebulæ have been found with the first 20-foot reflector of 12 inches aperture; figures of some of these given in Plate XVII.

442 Arrangement of nebulæ and clusters in *strata*, sometimes of great length.

443 Sun near the centre of the milky way. See Plate XVIII.

445 Star gauging defined.

446 Table of results of star gauging from $15^h\ 01^m$ to $16^h\ 37^m$ R. A. and from 92° to 94° N. P. D., and $11^h\ 16^m$ to $14^h\ 30^m$ and 78° to 80° N. P. D.

448 The solar motion explained by the situation of the sun in the milky way.

448 Local distribution of nebulæ—nebulæ are often surrounded by spaces vacant of stars.

449 Strata of *Cancer* and *Coma Berenices* described.

449 Although my single endeavors should not succeed in a work which seems to require the joint effort of every astronomer, yet so much we may venture to hope that by applying ourselves with all our powers to the improvement of telescopes, which I look upon as yet in their infant state, and turning them with assiduity to the study of the heavens, we shall in time obtain some faint knowledge of, and perhaps be able partly to delineate, the interior construction of the universe.

With this memoir is a plate of figures of nebulæ. Plate XVII, fig. 1, M. 98; 2, M. 53; 3, H., ii, 28 [resolvable]; 4, H., i, 18; 5, H, iii, 15; 6, H., iv, 5; 7, H, iv, 2; 8, H, iv, 3; 9, 10; 11, H, i, 13; 12, 13, 14, 15?

Also Plate XVIII, construction of the heavens—cloven disk.

1785 75 40 *Catalogue of Double Stars.* By WILLIAM HERSCHEL, Esq., F. R. S. Read December 9, 1784.

40 Introductory remarks. The great use of double stars having already been pointed out in a former paper on the Parallax of the Fixed Stars, and in a latter one on the Motion of the Solar System, I have now drawn up a second collection of 434 more, which I have found out since the first was delivered.

The method of classing them is in every respect the same as that which is used in the first collection.

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1785 75 41 Method of identifying and describing the positions of the stars.

43 I would recommend a precaution to those who wish to examine the closest of my double stars. It relates to the adjustment of the focus. Supposing the telescope and the observer long enough out in the open air to have acquired a certain temperature, and the night sufficiently clear, let the focus be readjusted with the utmost delicacy upon a star known to be single, of nearly the same altitude, magnitude, and color as the star to be examined.

44 Let the phenomena of the adjusting star be well attended to, as to whether it be perfectly rounded and well defined, or affected with little appendages, etc. Such deceptions may be detected by turning or unscrewing the object glass a little in its cell, when those appendages will be observed to revolve the same way.

44 Being thus acquainted with the imperfections as well as the perfections of the instrument, and going immediately from the adjusting star, we may hope to be successful.

45 All the observations here given were made with a power of 460 unless they are marked otherwise.

45 The measures were all taken with a parallel silk-worm's-thread micrometer and a power of 227 only, from the center of one star to the center of the other.

46 The threads subtend an angle of 1″ 13‴ only.

46 The positions have all been measured with a power of 460 on a micrometer made for me according to the model given in the *Phil. Trans.*, vol. lxxi, page 500, fig. 4.

W. HERSCHEL.

[Dated] Datchet, near Windsor, Nov. 1, 1784.

47 CATALOGUE OF DOUBLE STARS, FIRST CLASS. [Nos. 25 to 97.]

48 [Foot-note.] Could we increase our power and distinctness at pleasure we might undoubtedly separate any two stars that are not absolutely in a direct line. * * * This will appear when we consider that perhaps $\frac{59}{60}$ of the diameter of a star are spurious. It would have been curious if a considerable difference in the colors could have led us to discover which of the two stars is before the other! But by far the greatest part of their diameters being spurious, it is probable that a different-colored light of two stars would join together where the rays of one extend into those of the other; and so, producing a third color by the mixture, still leave the question undecided.

51 [Foot-note.] The interval between very unequal stars estimated in diameters generally gains more by an increase of magnifying power than the apparent distance of those which are nearer of a size. However, this only seems to take place when there is a difficulty of seeing the object well with a low power.

65 SECOND CLASS OF DOUBLE STARS. [Nos. 39 to 102.]

[Foot-note.] When the small star is so faint as not to bear the least illumination of the wires, its position may still be measured by the assistance of some wall or other object; for an eye which has been some time in the dark can see a wall in a starlight night sufficiently well to note the projection of the stars upon it in the manner which has been described with the lamp micrometer. Then introducing some light, and adapting the fixed wire to the observed direction

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of the stars on the wall, the moveable wire may be set to the parallel of the large star, which will give the angle of position pretty accurately.

1785 75 78 THIRD CLASS OF DOUBLE STARS. [Nos. 47 to 114.]

82 [Foot-note.] With regard to small stars that become visible by an increase of magnifying power, we may surmise that it is partly owing to the greater darkness of the field of view arising from the increased power, and partly to the real effect of the power.

83 [Foot-note.] The prismatic power of the atmosphere, of which little notice has been taken by astronomers, is that part of its refractive quality whereby it disperses the rays of light and gives a lengthened and colored image of a lucid point. It is very visible in low stars; *Fomalhaut*, for instance, affords a beautiful prismatic spectrum [experiments given], which explain also why a star is not always best in the center of the field of view; a fact I have often noticed before I knew the cause.

91 FOURTH CLASS OF DOUBLE STARS. [Nos. 45 to 132.]

105 FIFTH CLASS OF DOUBLE STARS. [Nos. 52 to 137.]

118 SIXTH CLASS OF DOUBLE STARS. [Nos. 67 to 126.]

126 Additional Errata to the Catalogue of Double Stars, Phil. Trans., vol. lxxii.

126 Plate V gives figures of 44 *Lyncis* and μ *Aurigæ*.

1785 75 213 *On the Construction of the Heavens.* By WILLIAM HERSCHEL, Esq., F. R. S. Read Feb. 3, 1785.

213 In an investigation of this delicate nature we ought to avoid two opposite extremes. If we indulge a fanciful imagination and build worlds of our own, we must not wonder at our going wide from the path of truth and nature. On the other hand, if we add observation to observation, without attempting to draw not only certain conclusions but also conjectural views from them, we offend against the very end for which only observations ought to be made. I will endeavor to keep a proper medium, but if I should deviate from that, I could wish not to fall into the latter error.

214 Theoretical view of the formation of nebulæ.

Form I. Condensation of neighboring stars about a central and larger star; globular forms.

215 *Form II.* Condensation of neighboring stars about a nucleus of contiguous stars; condensed irregular forms.

Form III. Condensation about a stream of stars, producing a form coarsely similar to the prototype: extended, branching, compound forms.

216 *Form IV.* Compound forms derived from the mutual attraction of clusters.

V. Vacancies will then arise in the surrounding space.

Objection to the above views; they tend to show a gradual destruction of the universe. Response, that space is infinite and that the occasional destruction of one star may operate to give life to the rest.

217 Optical appearances to an observer within a nebula of the third form.

219 Results of observation—star gauges.

221-240 Gauges throughout the 24^h in R. A. Results given in detail in a Table.

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A. D.	*Vol.*	*P.*	
1785	75	241	The stars being supposed to be nearly equally scattered, and their number in a field of view of known angular diameter being given, to determine the length of the visual ray. Solution of the problem.
		243	Another solution.
		244	*We inhabit the planet of a star belonging to a Compound Nebula of the third form.*
		244	Proof that the sun is situated in a compound nebula of Form III.
		250	*Use of the gauges.*
		253	*Section of our sidereal system.*
		254	*The origin of nebulous strata.*
		256	*An Opening in the Heavens.* M. 80 and M. 4 on the edges of vacancies.
		257	*Phenomena at the Poles of our nebula.*
		258	*Enumeration of very compound nebulæ or milky ways.* Ten described, including those of *Orion* and *Andromeda.*
		263	*A Perforated Nebula or Ring of Stars.* Account of nebula of *Lyra.* G. C., 4447.
			Planetary nebulæ. Observations of G. C., 4628, 4964, 4572, 4565, 826, 2102, 4302.
		266	The accompanying plate, viii, gives a figure of a section of the milky way.
1786	76	457	*Catalogue of one thousand New Nebulæ and Clusters of Stars.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read April 27, 1786.
		457	Description of sweeping telescope; Newtonian; 20 feet focus, 18.7 in. aperture, power 157, field 15′ 14″.
		458	Description of the method of sweeping.
		464	Probable errors of the places given by the sweeps before 1783, Dec. 13, $\Delta\alpha = 1^m$; $\Delta\delta$ 8′–10′, during 1784 $\Delta\alpha < 30^s$; $\Delta\delta < 5'$. Till 1785, September 24, $\Delta\alpha < 12^s$; $\Delta\delta < 4'$. Till 1786, April, $\Delta\alpha < 6^s$; $\Delta\delta < 2'$.
		466	When the diurnal motion of the earth was first maintained it could not but add greatly to the reception of this opinion when the telescope showed *Jupiter, Mars,* and *Venus* revolving on their axes; in the same way the view of so many sidereal systems will add credit to what I have said in regard to the construction of the heavens. For to the inhabitants of the nebulæ of the present catalogue our sidereal system must appear either as a small nebulous patch; an extended streak of milky light; a large resolvable nebula; a very compressed cluster of minute stars, hardly discernible; or as an immense collection of large scattered stars of various sizes, according as their situation is more or less remote from ours.
		466	Definition of *classes* of nebulæ and clusters.
		467	A map of positions of nebulæ was made for identification [by means of which the laws of aggregation of the nebulæ were gradually discovered].
		469	Explanation of a short method of describing the appearance of a nebula by letters.
		471	Catalogue:
		471	Class I No. 1 to No. 93
		473	II No. 1 to No. 402
		482	III No. 1 to No. 376
		492	IV No. 1 to No. 29
		493	V No. 1 to No. 24

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		494	Class VI No. 1 to No. 19
		496	VII No. 1 to No. 17
		496	VIII No. 1 to No. 40
		498	Notes to special nebulæ.
1786	76	500	*Investigation of the cause of that indistinctness of vision which has been ascribed to the smallness of the optic pencil.* By WILLIAM HERSCHEL, LL.D., F. R. S. Read June 22, 1786.
		500	Soon after my first essay of using high powers with the Newtonian telescope, I began to doubt whether an opinion which has been entertained by several eminent authors "that vision will grow indistinct when the optic pencils are less than the fortieth or fiftieth part of an inch" would hold good in all cases.
			I perceived that, according to this criterion, I was not entitled to see distinctly with a power much more than about 320 in a 7-foot telescope of an aperture of 6.4 inches; whereas in many experiments I found myself very well pleased with magnifiers which far exceeded such narrow limits.
			This induced me, as it were, by way of apology to myself for seeing well where I ought to have seen less distinctly, to make a few experiments.
		501	The first experiments I made were in 1778, and the result of them proved so decisive that I have never since resumed the subject, and had it not been for a late conversation with some of my highly esteemed and learned friends, I might probably have left the papers on which these experiments were recorded among the rest of those that are laid aside when they have afforded me the information I want.
		501	*Experiments with the naked eye.*
		502	*Microscopic experiments.*
			Exp. 3. With a pencil of $\frac{1}{232}$ of an inch I saw very distinctly.
		503	Exp. 4. With a pencil of $\frac{1}{724}$ of an inch I saw very distinctly.
			Exp. 5. With a pencil of $\frac{1}{1800}$ of an inch I saw very distinctly.
			Exp. 8. With a pencil of $\frac{1}{2173}$ of an inch I saw very distinctly.
		504	Exp. 10. It occurred to me that a certain proportion of aperture might be necessary to a given focal length of an object-glass or speculum.
		505	Exp. 10, 11, 12, 13, show that to see well in microscopes like the one used, the aperture of the object glass must bear a considerable proportion to its focal length.
		505	Exp. 15 shows that $\frac{1}{34}$th part of the focal length is not a sufficient aperture.
		507	As soon as convenient I intend to pursue this subject; at present my engagement with the work of a 40-feet reflector will hardly permit so much leisure, and till I have repeated, extended, and varied these experiments, I would wish them to be looked upon as mere hints.
1787	77	4	*Remarks on the new Comet.* In a letter from WILLIAM HERSCHEL, LL. D., F. R. S., to CHARLES BLAGDEN, M. D., Sec. R. S. Read Nov. 16, 1786. [Dated Slough, near Windsor, Nov. 15, 1786.] [This comet was discovered by CAROLINA HERSCHEL, August 1, 1786, during the absence of WILLIAM HERSCHEL on a visit to Germany. It was comet 1786, II.]

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1787	77	125	*An account of the discovery of two satellites revolving round the Georgian Planet.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read Feb. 15, 1787.
		125	I had frequently directed large telescopes to this remote planet to see if it were attended by satellites, but failed for the want of sufficient light in the instruments I used.
		126	In the beginning of [January, 1787] I found that my telescope used as a *front view* gave much more light. On the 11th of January I selected a sweep which included the *Georgian Planet,* and noted down the places of the small stars near it. The next day two of these were missing. To satisfy myself I noted down all the small stars on the 14th, 17th, 18th, and 24th of January, and the 4th and 5th of February, and though I had no longer any doubt of the existence of at least one satellite, I thought it right to defer this communication till I could see it actually in motion. Accordingly I began to pursue this satellite on February the 7th, at about 6 o'clock in the evening, and kept it in view till three in the morning on Feb. the 8th, and during those nine hours I saw this satellite faithfully attend its primary planet and describe a considerable arc of its proper orbit.
		126	While I was attending to the motion of this satellite I did not forget to follow another small star which I was pretty well assured was also a satellite.
		127	The first-discovered satellite [*Oberon*] is the farthest from the planet and I shall call it the *second satellite;* the last-discovered [*Titania*] I shall call the *first satellite.*
		127	I made a sketch on paper to point out beforehand the situation of these satellites on Feb. 10, and [on that night] the heavens displayed the original of my drawing by shewing, in the situation I had delineated them, *the Georgian Planet attended by two satellites.* I confess that this scene appeared to me with additional beauty as the little secondary planets seemed to give a dignity to the primary one which raises it into a more conspicuous situation among the great bodies of our solar system.
		128	I suppose the *first* performs a synodical revolution in about 8¾ days, the *second* in nearly 13½ days. Their orbits make a considerable angle with the ecliptic.
		129	Attempts to measure them with my micrometers have so far failed. I have nevertheless several resources in view and do not despair of succeeding pretty well in the end. W. HERSCHEL. [Dated] Slough, near Windsor, February 11, 1787.
1787	77	229	*An account of Three Volcanoes in the Moon.* By WILLIAM HERSCHEL, LL. D., F. R. S.; communicated by Sir JOSEPH BANKS, Bart., P. R. S. Read April 26, 1787.
		229	The phenomena of nature are to be viewed not only with the usual attention to facts as they occur, but with the eye of reason and experience. In this we are not allowed to depart from plain appearances. Thus when we see on the surface of the moon a great number of elevations from half a mile to a mile and a half in height we are strictly entitled to call them mountains; but when we attend to their particular shape, in which many of them resemble the craters of our volcanoes, and thence argue that they owe their origin to the same cause which has modeled many of these, we may be said to see by analogy, or with the eye of reason.

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1787	77	229	In this latter case, though it may be convenient to use expressions which can only be justified by reasoning upon the facts themselves, it will certainly be the safest way not to neglect a full description of them, that it may appear to others how far we have been authorized to use the mental eye.
1787	77	230	April 19, 1787, $10^h\ 36^m$ sidereal time, three volcanoes seen; April 20, 1787, $10^h\ 2^m$ sidereal time, one of the three burns with greater violence than last night. The diameter of the volcano is twice that of *Jupiter's* satellite III.
		231	The appearance of the actual fire exactly resembled a small piece of burning charcoal when it is covered with a very thin coat of white ashes. All the adjacent parts of the volcanic mountain seemed to be faintly illuminated by the eruption and were gradually more obscure as they lay at a greater distance from the crater. This eruption resembled much that which I saw on the 4th of May, 1783,* an account of which I shall shortly lay before the society. WILLIAM HERSCHEL.
			[Dated] Slough, near Windsor, April 21, 1787.
		232	Note on M. MÉCHAIN'S comet. [1787, I.]
1787	77	364	*On the Georgian Planet and its satellites.* By WILLIAM HERSCHEL, LL. D. F. R. S. Read May 22, 1788.
			In a former paper I gave the periodical times of two satellites revolving round the *Georgian Planet* in a general way. While it requires a much longer series of observations than I have had an opportunity of making to settle their mean motions with accuracy, I shall communicate the result of my past observations, and believe that the elements here delivered will be found to be full as accurate as we can at this time expect.
		365	Methods of measuring angles of position which were employed.
		365	Synodical revolution of Satellite I = $8^d\ 17^h\ 1^m\ 19.3^s$. [*Titania.*]
		365	Synodical revolution of Satellite II = $13^d\ 11^h\ 5^m\ 1.5^s$. [*Oberon.*]
		366	Other elements.
		368	Mass of [*Uranus*] is 17.740612 times the earth's mass.
		369	Diameter of [*Uranus*] is assumed 4″.04625.
		370	Difficulties in making the measures of satellites stated.
		371	Measures of Satellite I and discussion of these.
		376	The light of these satellites is uncommonly faint. The second [*Oberon*] is the brighter of the two, but the difference is not considerable.
		377	Elements of the orbits. W. HERSCHEL.
		378	Plate V of diagrams. [Dated] Slough, March 1, 1788.
1789	79	151	*Observations on a Comet.* In a letter from WILLIAM HERSCHEL, LL. D., F. R. S., to Sir JOSEPH BANKS, Bart., P. R. S. Read April 2, 1789. Letter dated Slough, March 3, 1789. [This was comet 1788, II.]
		151	The comet was discovered by CAROLINA HERSCHEL, December 21, 1788, and positions of it on December 22, 1788, are given.
		153	No solid nucleus, even so small as 1″, could be seen, and the same fact has been observed by me in three other comets.
1789	79	212	*Catalogue of a second thousand of New Nebulæ and Clusters of Stars; with a few introductory Remarks on the Construction of the Heavens.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 11, 1789.
		213	A telescope has power to penetrate into space. Proof that every star is a sun shining by its native brightness.

* *This observation* is reported by Baron von TACH in BODE'S Jahrbuch, 1788, p. 144.

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1789	79	214	Systems of stars—globular clusters and definition of a cluster.
		216	Admitting that a cluster is real, not apparent, the stars composing it are about of equal magnitude.
		217	At the same distance from the centre an equal scattering takes place.
		217	These clusters are of a globular form.
		218	They are more condensed at the centre than at the surface.
		219	Form I of nebulæ [*Phil. Trans.*, 1785, p. 214], is thus shown to exist in the heavens.
		219	Such clusters are subject to central powers.
		220	The idea of other central forces [than that of gravity] in the construction of the sidereal heavens, was given in certain mathematical papers delivered to the Philosophical Society of Bath [and is yet entertained].
		221	Not only were *round* nebula and clusters formed by central powers, but likewise every cluster of stars or nebula that shows a gradual condensation, or increasing brightness towards a centre.
		222	This theory of central power is fully established on grounds [of observation] which cannot be overturned.
		223	Clusters can be found of 10′ diameter with a certain degree of compression and stars of a certain magnitude, and smaller clusters of 4′ 3′ 2′ in diameter, with smaller stars and greater compression, and so on through resolvable nebulæ by imperceptible steps, to the smallest and faintest [and most distant] nebulæ.
		224	Other clusters there are, which lead to the belief that either they are more compressed or are composed of larger stars. Spherical clusters are probably not more different in size among themselves than different individuals of plants of the same species. As it has been shown that the spherical figure of a cluster of stars is owing to central powers, it follows that those clusters which, *cæteris paribus*, are the most complete in this figure, must have been the longest exposed to the action of these causes.
		225	The maturity of a sidereal system may thus be judged from the disposition of the component parts. Planetary nebulæ may be looked on as very aged.
		226	This method of viewing the heavens seems to throw them into a new kind of light. They are now seen to resemble a luxuriant garden which contains the greatest variety of productions in different flourishing beds; and one advantage we may at least reap from it is that we can, as it were, extend the range of our experience to an immense duration. For, is it not almost the same thing whether we live successively to witness the germination, blooming, foliage, fecundity, fading, withering, and corruption of a plant, or whether a vast number of specimens, selected from every stage through which the plant passes in the course of its existence, be brought at once to our view? WILLIAM HERSCHEL. [Dated] Slough, near Windsor, May 1, 1789.
		226	Catalogue:
		226	Class I No. 94 to No. 215
		229	II No. 403 to No. 768
		238	III No. 377 to No. 747
		246	IV No. 30 to No. 58
		248	V No. 25 to No. 44
		250	VI No. 20 to No. 35

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1789	79	251	Class VII No. 18 to No. 55
		253	VIII No. 41 to No. 78
		255	Notes.
		255	P. S.—The planet *Saturn* has a *sixth satellite* revolving round it in about 32 hours 48 minutes. Its orbit lies exactly in the plane of the ring. An account of its discovery with the 40-foot reflector, etc., will be presented to the Royal Society at their next meeting. William Herschel.
1790	80	1	*Account of the discovery of a sixth and seventh satellite of the planet Saturn; with remarks on the construction of its ring, its atmosphere, its rotation on an axis, and its spheroidical figure.* By William Herschel, LL. D., F. R. S. Read November 12, 1789.
		1	In a postscript to my last paper I announced to the Royal Society the discovery of a satellite of *Saturn*. I have now the honor to present them, with an account of two satellites instead of one, and I have called them the *sixth* and *seventh*, although their situation very probably entitles them to be called the first and second.
		2	These have not been before discovered on account of the difficulty of seeing them with a less telescope than the 40-foot.
		2	I began to observe *Saturn* in 1774, and on March 17 I saw it with a 5½-foot reflector, as in Plate I, fig. 1. Fig. 2 shows it on April 3, 1774, without its ring. In 1775 I saw the ring gradually open (using a 7-foot reflector). Fig. 3, Plate II, shows the appearance 1783 [should be 1778], June 20 (with a very good 10-foot reflector).
		3	The black belt on the ring of *Saturn* is not in the middle of its breadth, nor is the ring subdivided by many such lines, but there is one single, considerably broad belt upon the ring which is permanently in its place.
		3	My observations show that this belt (at least on the north half of the ring, where I have alone observed it) is not like the belts of *Jupiter* or those of *Saturn*, subject to variations of color or figure, but is most probably owing to some permanent construction of the surface of the ring itself.
		3	It is not the shadow of a chain of mountains, since it is visible all round the ring. The same argument will hold good against supposed caverns or concavities. It is pretty evident that it is contained between two concentric circles. See fig. 4, Plate II, drawing of 1780, May 11.
		4	As to the surmise of two rings, it does not appear eligible to venture on so artificial a construction, by way of explaining a phenomenon, which does not absolutely demand it.
		4	As yet we do not know of any rotation of the ring which may be of such a proper velocity as [might lend some support to the idea of two detached rings].
		5	If the southern side of the ring should be differently marked, it would negative the idea of two rings. Even if it should be marked the same in every respect, it would be best to wait for the occultation of some considerable star by *Saturn*, when, if the ring be divided, it will be seen between the openings of the ring, as well as between the ring and *Saturn*.
		5	We may certainly affirm that the ring is no less solid than the planet itself. The reasons which prove the solidity of one serve to prove *that of* the other.

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1790 80 5 The mass of the planet, as determined from the satellites, includes that of the ring; and the ring produces irregularities in the motions of the satellites, as does also the oblateness of the ball of the planet.

5 The light of the ring is brighter than that of the planet. [Proof given.]

6 The ring is extremely thin for—

1789, July 18, [*Tethys*] was thicker than the ring;
——, July 23, [*Dione*] was twice as thick as the ring;
——, July 27, [*Enceladus*] was thicker than the ring;
——, August 29, [*Mimas*] was thicker than the ring;
1789, Oct. 15: the ring was barely visible in the 40-foot reflector, but [*Enceladus*] was visible about the middle of the preceding arm.
1789, Oct. 16: I followed [*Mimas* and *Enceladus*] up to the very disc of the planet.

7 A suspicion arises that by a refraction through some very rare atmosphere on the ring the satellites might be lifted up and depressed so as to be visible on both sides of the ring.

8 The edge of the ring is very probably not square, but spherical or spheroidical.

8 The ring cannot possibly disappear on account of its thinness.

8 I formerly supposed the surface of the ring to be rough, owing to
9 luminous points like mountains seen on the ring, till one of these supposed luminous points was kind enough to venture off the edge of the ring and appear as a satellite. As I had noted all such inequalities I could calculate all such surmises, and I have always found these appearances to be due to satellites.

9 Upon the whole, I cannot say that I had any one instance that could induce me to believe the ring was not of a uniform thickness; that is, equally thick at equal distances from the centre and of an equal diameter throughout.

10 Strong suspicions of the existence of a sixth satellite I have long entertained. I saw it 1787, August 19. I was then busy with the Georgian satellites.

10 In 1788 my 20-foot speculum was much tarnished.

10 The very first moment I turned my 40-foot telescope on *Saturn*, 1789, August 28, I saw six satellites, and on September 17 I detected the seventh satellite.

11 From many observations of the sixth satellite [*Enceladus*] I find its sidereal revolution $1^d\ 8^h\ 53^m\ 9^s$, and by computation its distance $35''.058$. Its light is considerably strong, but not equal to that of [*Tethys*].

12 The seventh satellite [*Mimas*] makes one sidereal revolution in $22^h\ 40^m\ 46^s$; its distance (computed) is $27''.366$.

12 It is incomparably smaller than [*Enceladus*], and even in the 40-foot reflector appears no bigger than a very small lucid point; to which the exquisite figure of the speculum not a little contributes.

13 The orbits of these two satellites are exactly in the plane of the ring.

13 Observations of the belts and figure of *Saturn* from April 9, 1775, to Sept. 8, 1780, and reference to [rough] figures are here given.

15 We may draw two conclusions from these: *First, Saturn* has probably a very considerable atmosphere. The changes in the belts show

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this, and also the hanging of the satellites on the limb; the time of hanging on the limb for *Mimas* has actually amounted to 20 minutes. This would denote a refraction of about 2″ [provided, etc.].

1790 80 16 The *second* conclusion is that *Saturn* turns on an axis perpendicular to the ring. The proof depends on the position of the belts which for 14 years have been [nearly] always equatorial.

17 Another reason is that *Saturn*, like *Jupiter*, *Mars*, and the earth, is flattened at the poles, and therefore ought to be supposed to turn on its axis. [Observations 1776, July 22, to 1789, Sept. 14, given.]

On the last date equatorial diameter 22″.81 (4).
polar diameter 20″.61 (4).

18 The equatorial is to the polar diameter nearly as 11 to 10.

18 One beautiful observation of the transit of [*Titan*] over the disc I must add, of 1789, November 2.

WILLIAM HERSCHEL.

[Dated] Slough, near Windsor, November 3, 1789.

1790 80 427 *On the Satellites of the planet Saturn and the rotation of its Ring on an Axis.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 7, 1790.

427 The observations to be given extend from July 18 to Dec. 25, 1789. On calculating the appearances of bright luminous points on the ring, I found that all of them could not be accounted for by satellites.

428 The question, then, is, what to make of these protuberant points?

428 To admit two or three more satellites appears too hazardous. And yet a suspicion of at least one more satellite would often return.

428 The observations of each satellite have been separated, and at least one observation of each has been calculated for each night.

429 Fig. 1, Plate XIX, p. 494, gives a scheme of the orbits. Explanation of this figure and of the tables.

432 *Observations on the fifth satellite of Saturn* [*Japetus*].

438 *Observations on the fourth satellite of Saturn* [*Titan*].

441 1789, Nov. 2. Transit of *Titan's* shadow.

444 *Observations on the third satellite of Saturn* [*Rhea*].

447 1789, Oct. 16. The color of *Rhea* is inclining to blue.

450 *Observations on the second satellite of Saturn* [*Dione*].
1789, Sept. 25. Probable occultation of *Dione* by *Tethys*.

456 *Observations on the first satellite of Saturn* [*Tethys*].

463 *Observations on the sixth satellite of Saturn* [*Enceladus*].
1789, Oct. 16. Occultation by *Saturn*.

473 *Observations on the seventh satellite of Saturn* [*Mimas*].
1789, Oct. 16. Occultation by *Saturn*.

478 The motions of these 7 satellites are so well known that no shape of lucid spot, protuberant point, or latent satellite can be occasioned by any one of them without our knowing it. I found that the observations to be given presently could not be explained by any of the known satellites.

478 The first idea was of another satellite interior to the 7th; and if a revolution slower than about 15¼ hours could have been found to account for most of the places where the bright spots were seen, I should have believed these to be caused by an 8th satellite. This being impracticable, I examined what would be the result if these *bright* points were attached to the plane of the ring.

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1790 80 479 As observations, carefully made, should always take the lead of theories, I shall not be concerned if what I have to say contradicts what has been said in my last paper.

479 A lucid and apparently protuberant point may exist without any great inequality in the ring. A vivid light, for instance, will seem to project greatly beyond the limits of the body upon which it is placed.

479 The brightest and best-observed spot agrees to a revolution of $10^h\ 32^m\ 15^s.4$ at a distance of $17''.227$, *i. e.*, on the ring. Therefore, unless the ring is fluid, or has a groove in it, so as to let the satellite revolve in it, we ought to admit a revolution of the ring itself.

480 It seems almost proved that the consistence of the ring is not less than the body of Saturn; consequently no sufficient degree of fluidity can be admitted.

481 *Observations not accounted for by satellites* [are given].

487 Epochs of six of the satellites given.

487 Period of *Enceladus* $1^d\ 8^h\ 53^m\ 8^s.9$; distance $36''.7889$.
" " *Mimas* $0^d\ 22^h\ 37^m\ 22^s.9$; " $28''.6689$.

488 Tables for the seven satellites of Saturn.

495 Example of the use of the tables.

1791 81 71 *On Nebulous Stars, properly so called.* By William Herschel, LL. D., F. R. S. Read February 10, 1791.

71 In one of my late examinations of the heavens I discovered *a star of about the 8th magnitude, surrounded with a faintly luminous atmosphere of a considerable extent.*

71 The name nebulous stars was incorrectly used in former times.

71 The milky way itself consists entirely of stars.

72 Nebulæ can be selected so that an insensible gradation shall take place from a coarse cluster like the *Pleiades* down to a milky nebulosity like that in *Orion*, every intermediate step being represented. This tends to confirm the hypothesis that all are composed of stars more or less remote.

73 A comparison of the two *extremes* of the series, as a coarse cluster and a nebulous star, indicates, however, that *the nebulosity about the star is not of a starry nature.*

74 Summary of the reason which formerly led to the belief that all nebulæ were clusters more or less remote.
Basis for the ideas of *connection* and *disjunction* of stars and nebulæ.

75–77 Particular examples of such supposed conjunctions and disassociations. Telescopic milky way of over 60 square degrees.
The trapezium of *Orion* is unconnected with the nebula.

78–82 Notes of observations on nebulous stars and consideration of the relation of the nucleus to the envelope in each case.

83 Considering H, iv 69, [= G. C. 810,] as a typical nebulous star, and supposing the nucleus and chevelure to be connected, we may, 1st, suppose the whole to be of stars, in which case either the nucleus is enormously larger than other stars of its stellar magnitude or the envelope is composed of stars indefinitely small; or, 2d, we must admit that the star is involved in a shining fluid of a nature totally unknown to us.

84 Perhaps it has been too hastily surmised that all milky nebulosity is owing to starlight only.

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The *telescopic milky way* is probably composed of this shining fluid, which must commence somewhere about the range of the stars of the 7th magnitude, and extend to the regions of the 9th, 10th, 11th, and 12th.

1791 81 85 The shining fluid might exist independently of stars. The light of this fluid is no kind of reflection from the star in the center. If this matter is self-luminous, it seems more fit to produce a star by its condensation than to depend on the star for its existence.

86 List of diffused nebulosities and planetary nebulæ; both better accounted for by the hypothesis of a shining fluid than by supposing them to be distant stars.

Regeneration of stars from planetary nebulæ.

87 How far the light-corpuscles emitted from millions of suns may be concerned in this shining fluid it is not necessary to inquire. We need not know the origin of the luminous matter whose existence is rendered evident by means of nebulous stars.

W. HERSCHEL.

[Dated] Slough, January 1, 1791.

1792 82 1 *On the Ring of Saturn and the rotation of the fifth satellite upon its axis.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read December 15, 1791.

1 In a former paper (*Phil. Trans.*, vol. lxxx, p. 4) I spoke of the surmise of a division in *Saturn's* ring with proper doubts. My late views of the southern side of the ring and the discovery of its quick rotation enable me to speak decisively.

2 The black division is always of the same breadth if we leave out of account certain very small variations which I have occasionally observed.

3 *Observations on the Ring of Saturn* (from 1790, Sept. 7, to Oct. 24).

4 From these and former observations I think myself authorized now to say that the planet *Saturn* has two concentric rings. * * *

5 The relative dimensions of the rings and spaces are given in a table.

5 This opening in the ring (which is some 2,513 miles in width) must be of considerable service to the planet, in reducing the space that is eclipsed by the shadow of the ring.

6 It becomes a question if both rings revolve in the same time. The period formerly given (*Phil. Trans.*, lxxx, p. 481), belongs to the outer ring. The former observations indicate that the inner ring revolves with great velocity on its axis, but are not sufficient to determine the period.

7 It is quite probable that there should be a small difference in the periods of the two rings.

7 A memoir (in *Histoire de l' Académie Royale des Sciences de Paris*, 1787, p. 249—) refers to observations of many divisions of the ring of *Saturn*.

8 My own observations of *Saturn* since 1774 contain only four where any other black division upon the ring is mentioned than the one I have constantly observed. These 4 observations were in 1780—(see Plate I, figs 1, 2, 3.)

9 *Saturn* was then in the very best situation for viewing the plane of the ring, but I have hitherto set these observations aside as wanting more confirmation.

9 Observations have been made by M. CASSINI, Mr. SHORT, and Mr. HADLEY [and are referred to].

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1792 82 11 It does not appear to me that there is a sufficient ground for admitting the ring of *Saturn* to be of a very changeable nature.

11 Measures of the diameter of the outer ring, reduced to the mean distance of *Saturn* from the earth; 46″.832; 47″.241; 45″.803;

13 *On the rotation of the fifth satellite of Saturn, on its axis.*

The fifth satellite [*Japetus*] is subject to a change of brightness; this having been noticed by other observers I did not at first pay so much attention to it as it deserved. I afterwards followed this satellite with great attention and marked all its changes of apparent brightness.

13 The result of many observations is as follows: The light of the satellite is in full splendor during the time it runs through that part of its orbit, which is between 68 and 129 degrees past the inferior conjunction. In this arc it does not fall above one magnitude short of the brightness of [*Titan*].

14 From about 7° past the opposition till towards the inferior conjunction it is not only less bright than [*Rhea*] but hardly, if at all, exceeds [*Dione*]; or even [*Tethys*] at elongation. Such a change among the fixed stars and to the naked eye would be from the 2d to the 5th magnitude.

14 It is now evident that the time of its rotation on its axis cannot differ much from the time of its revolution about *Saturn;* notwithstanding that the light of the satellite has suffered an occasional change of short duration from other causes.

14 But I may go further and ascertain upon sufficient grounds, that this satellite turns once upon its axis exactly in the time it performs one revolution. This degree of accuracy is obtained by taking in the observations of M. CASSINI in *Mémoires de l'Acad. Roy. des Sciences*, 1705, p. 121; (see, also, 1707, p. 96), and those of M. BERNARD, *op. cit.*, 1786, p. 378.

16 Joining all these I conclude that the 5th satellite of *Saturn* turns upon its axis once in 79 days 7 hours and 47 minutes.

16 I cannot help reflecting with some pleasure on the discovery of an analogy which shows that a certain uniform plan is carried on among the secondaries of our solar system; and we may conjecture that probably most of the satellites are governed by the same law, especially if it be founded on such a construction of their figure as makes them more ponderous toward their primary planets.

17 From the changes in [*Japetus*] we may conclude that some part of its surface, and this by far the largest, reflects much less light than the rest; and that neither the darkest nor the brightest side of the satellite is turned toward the planet, but partly one and partly the other, though probably less of the bright side.

17 The great regularity of this change of brightness seems to point out another resemblance of this satellite with our moon. We see the spots on the moon of pretty nearly the same brightness, so as not to be overcast in a very strong degree by dense clouds to disfigure them, and therefore have great reason to surmise that her atmosphere is extremely rare; in like manner we may suppose the atmosphere of *Japetus* as rare as that of our moon.

17 *On the distance of the fifth satellite.*

Many measures have been made for the purpose of getting the mass. They begin 1791, Sept. 25, and end Oct. 1.

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1792 82 23 *Miscellaneous observations.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read December 22, 1791.

23 *Account of a Comet.* [1792, I.] This was discovered by CAROLINA HERSCHEL, 1791, Dec. 15. Examined Dec. 16 with a 20-foot reflector; brief description and position for Dec. 16.

24 *On the periodical appearance of o Ceti.*

25 331 days 10^h 19^m is its period.

26 *On the disappearance of the* 55th *Herculis.*

1781, Oct. 10, I examined both 54 and 55 *Herculis;* again 1782, April 11; 1790, May 24, 55 *Herculis* was missing, and although looked for has not again been seen.

27 *Remarkable Phenomena in an eclipse of the Moon.*

1790, Oct. 22, when the moon was totally eclipsed I viewed the disc with a 20-feet reflector with power 360. In several parts of it I perceived many bright, red, luminous points. Most of them were small and round, at least 150 of them. Their light did not much exceed that of *Mons Porphyrites Hevelii.*

We know too little of the surface of the moon to venture at a surmise of the cause from whence the great brightness, similarity, and remarkable color of these points could arise. (Dated) Slough, December 17, 1791.

1793 83 201 *Observations on the Planet Venus.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 13, 1793.

201 A series of observations on *Venus* begun in April, 1777, has been continued down to the present time. The first object of the research was to determine the diurnal rotation, for the observations of CASSINI and BIANCHINI can leave no doubt but that it has a rotation on its axis; the second was the atmosphere of *Venus,* of the existence of which, after a few months' observations, I could not entertain the least doubt; and third, the investigation of the real diameter. To which may be added an attention to the construction of the planet with regard to permanent appearances, such as might be ascribed to seas, continents, or mountains.

202 The result of my observations would have been communicated long ago if I had not flattered myself with the hope of some better success concerning the diurnal motion of *Venus,* which has still eluded my constant attention as far as concerns its period and direction.

202 Even at this present time I should hesitate to give the following extracts if it did not seem incumbent upon me to examine by what accident I came to overlook mountains in this planet "*of such enormous height as to exceed four, five, or even six times the perpendicular elevation of Chimboraço, the highest of our mountains.*" [Quoted from SCHROETER, *Phil. Trans.* 1792, p. 337.]

202 The same paper contains other particulars concerning *Venus* and *Saturn.* All of which being things of which I have never taken any notice, it will not be amiss to show by what follows that neither want of attention nor a deficiency of instruments could occasion my not perceiving *these mountains of more than* 23 *miles in height; this jagged border of Venus; and these flat spherical forms on Saturn.*

203 Before I remark on the rest of the extraordinary relations above mentioned I will give a short extract of my observations of *Venus.*

203 *Observations* from 1777, April 17, to 1793, May 20.

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1793	83	204	The observations and drawings (one given in Plate XXII, fig 1), 1780, June 19, 21, 23, 24, 25, 26, 28, 29, 30, and July 3, showed that *Venus* has a motion on her axis, and as evidently that she has an atmosphere.
		206	1789, Nov. 30: no satellite visible; if she has one it must be below 8 or 9 magnitude.
		206	Two measures of the diameter, 1791, Nov. 24.
		215	My observations show that the atmosphere of *Venus* is of much greater extent or refractive power than as given in the paper [of SCHROETER.]
		216	As to the mountains in *Venus*, I may venture to say that no eye which is not considerably better than mine, or assisted by much better instruments, will ever get a sight of them.
		217	The diameter of *Venus* at the mean distance of the earth is 18″.79.
		218	The appearance of the luminous border of *Venus* as I have described it, *i. e., suddenly much brighter all around the limb*, has not been noticed by the author we have referred to.
		218	The cause of this appearance may probably be ascribed to the atmosphere of *Venus*, which is probably replete with matter that reflects and refracts light copiously. Therefore on the border, where we have an oblique view, there will be an increase of this appearance.
1794	84	28	*Observations of a quintuple belt on the Planet Saturn.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read December 19, 1793.
		28	In some of my former papers I have established the spheroidical form of *Saturn* and pointed out the motion of a spot on its disc. From the first we infer a rotation on its axis; the second shows that it has such a motion.
			My late observations seem to hint to us that the period of rotation is not of long duration.
		28	Observations of the quintuple belt; see Plate VI, fig. 1.
		30	Observations of belts on *Jupiter;* see Plate VI, fig. 2, fig. 3.
		31	Belts are connected with the rotation of the planets. Since then it appears that the belts of *Saturn* are very numerous, like those of *Jupiter*, and are also placed in the direction of the longest diameter of the planet, it may not be without some reason that we infer the period of the rotation of the former to be short like that of the latter.
		31	I have never seen parallel belts on *Mars* nor on *Venus*.
1794	84	39	*Account of some particulars observed during the late eclipse of the sun.* [1793, September 5.] By WILLIAM HERSCHEL, LL. D., F. R. S. Read January 9, 1794.
		39	Observations. See Plate VII, figs. 1, 2, 3.
		39	At first contact two mountains of the moon were seen on the sun; see fig. 1.
		41	The cusps of the sun attentively inspected, and I suspected a little bending of the cusps outward as in fig. 4; but I could not satisfy myself of its reality. If there was a bending, it did probably not amount to 1″.
		41	[Foot-note.] In 1779, 1780, 1781, I measured the heights of about 100 mountains of the moon by three different methods. Some of these observations are given in *Phil. Trans.*, Vol. lxx, p. 507, but most remain uncalculated in my journal till some proper opportunity. WM. HERSCHEL.
			[Dated] Slough, near Windsor, Dec. 30, 1793.

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1794 84 48 *On the rotation of the planet Saturn upon its axis.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read January 23, 1794.

48 In a late paper I pointed out an analogy which might lead us to surmise that *Saturn* had a quick rotation on its axis. I can at present announce the reality of that rotation by means of observations of 154 revolutions of the planet.

48 The belts of *Saturn* that I have been observing seem to have undergone no material change for the last two months.

48 I give the observations upon which my computations have been founded, entire.

49–59 *Observations on the belts of Saturn.*

50 [Foot-note.] In the course of these observations I made 10 new object specula and 14 small plain ones for my 7-foot reflector, having found that a 7-foot reflector was adequate to my purpose.

51 [Foot-note.] These objectives were from 84 to 88 inches focus, and were used with an eye-glass of $\frac{3}{10}$ of an inch focus, the power thus being from 280 to 293.

52 I took care to bend my head so as to receive the picture of the belt in the same direction upon the retina as I did [formerly].

52 [Foot-note.] This was a precaution that occurred to me, as there was a possibility that the vertical diameter of the retina might be more or less sensible than the horizontal one; but I had no reason afterward to suppose that any such difference really exists.

53 *Observation upon the double ring of Saturn.*

The outer ring is less bright than the inner ring. The inner ring is very bright close to the dividing space; and at about half its breadth it begins to change color, gradually growing fainter.

54 There is a dry wind and the telescope will not show objects as distinct as when moisture is discharged from the air by the precipitation of dew.

55 *Remark on the shadow of Saturn and its rings.*

On the ring is the shadow of the body. The shadow of the ring upon the body of the planet close to the ring is not parallel to the ring at the two extremes, but a little broader there than in the middle, the ends turning toward the south.

56 *The five old satellites* are all seen with a power of 60 on a 10-foot reflector.

57 *Observations of the south pole of Saturn and the shadow of the ring.*

The south polar regions of *Saturn* are a little brighter than they used to be; they are almost as bright as that belt. The shadow of the ring upon Saturn is perfectly black, like the shadow of *Saturn* upon the ring. The shadow of the ring upon *Saturn* on each side is bent a little southward.

58 *Trial of concave eye-glasses.*

With regard to the field of view, they are full as convenient as convex glasses.

59 *Determination of the period of the rotation of Saturn.* Explanation of Plate IX and the method of obtaining the period from the observations.

60 The first trial gives $10^h\ 15^m\ 40^s$ for the time of 1 revolution.

The second trial gives $10^h\ 16^m\ 51^s$ for the time of 1 revolution.

61 The third trial gives $10^h\ 17^m\ 54^s$ for the time of 1 revolution.

The fourth trial gives $10^h\ 17^m\ 6^s$ for the time of 1 revolution.

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1794	84	61	I take the mean of the first two, $10^h\ 16^m\ 15^s.5$, for the approximate rotation period.
		62-3	Tables for the motion of the equator of *Saturn*.
		64-5	Comparison of observation with the tables.
		66	We may conclude that the period is exact to $\pm 2^m$, and we need not hesitate to fix the rotation of *Saturn* upon its axis as $10^h\ 16^m\ 0^s.4$. WM. HERSCHEL.
			[Dated] Slough, near Windsor, Jan. 22, 1872.
1795	85	46	*On the Nature and Construction of the Sun and Fixed Stars.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read December 18, 1794.
		46	The sun is the celestial body which should first attract our notice, not only on its own account but since the fixed stars are, by the strictest analogy, similar bodies.
		46	NEWTON has shown that the sun retains the planets of our system in their orbits;
		47	BRADLEY has assigned the velocity of the solar light; GALILEO, SCHEINER, HEVELIUS, CASSINI and others have ascertained its rotation and the place of its equator. The Transit of Venus has given means to calculate its distance, its real diameter, magnitude, density, and the fall of heavy bodies on its surface. Thus we have already a clear idea of the powerful influence of the sun.
		47	I should not wonder if [considering what we know] we were induced to think that nothing remained to be added; and yet we are still very ignorant in regard to the internal construction of the sun.
		47	The spots have been supposed to be solid bodies, the smoke of volcanoes, the scum floating on an ocean of fluid matter, clouds, opaque masses, and to be many other things.
		48	The sun itself has been called a globe of fire, though perhaps metaphorically.
		48	The faculæ have been called luminous vapors, etc.
		48	The light of the sun itself has been supposed invisible and not to be perceived except by reflection, though the proofs seem to me to amount to no more than saying that we cannot see when rays of light do not enter the eye. But it is time now to profit by the observations we are in possession of.
		48	I have availed myself of the labors of preceding astronomers, but have been induced thereto by my own actual observation of the solar phenomena.
		49	Following is a short extract of my observations. In 1779 there was a spot on the sun, divided into two parts, the largest above 31,000 miles in diameter. Both together must have extended above 50,000. The idea of its being occasioned by a volcanic explosion ought to be rejected.
		50	We have pretty good reason to believe that all the planets emit light in some degree.
		50	Example of the illumination of the moon during an eclipse, which could not have been due to the light from the earth.
		51	The dark half of *Venus* has been seen by different persons.
		51	In regard to the large spot on the sun, I concluded that I viewed the real solid body of the sun itself, of which we rarely see more than its shining atmosphere.
		51	Description of a large spot seen in 1783: the spot was plainly depressed below the surface of the sun.

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1795	85	51	Explanation of the luminous shelving sides of a sun-spot. The sun may have inequalities [like mountains] on its surface perhaps 500 or 600 miles high.
		53	In 1791 I observed a large spot on the sun, depressed below the level of its surface.
		53	An optical deception takes place now and then when we view the moon, which is that all the elevated spots on its surface will seem to be cavities, and *vice versa*.
		54	How very ill would these observations agree with the ideas of solid bodies bobbing up and down in a fiery liquid? with the smoke of volcanoes or the scum upon an ocean?
		54–58	Observations in detail from 1792, Aug. 26, to 1794, Oct. 13.
		54	1792, Sept. 2. Two spots on the sun were seen with the naked eye.
		55	It may not be impossible, as light is a transparent fluid, that the sun's real surface may also now and then be perceived, as we see the shape of the wick of a candle through its flame.
		56	Faculæ seem generally to accompany the spots, and they are certainly elevations on the surface.
		57	The sun cannot be so distinctly viewed with a small aperture and faint darkening glasses as with a large aperture and stronger ones.
		57	About all the spots the shining matter seems to have been disturbed, and is uneven, lumpy, and zig-zagged in an irregular manner.
		57	I call the spots black, not that they are entirely so, but to distinguish them. There is not one of them to-day which is not at least partly covered over with whitish and unequally bright nebulosity.
		58	If the brightness of the sun is occasioned by the lucid atmosphere the intensity of the brightness must be less where it is depressed.
			The results of these observations are: The sun has a very extensive atmosphere, which consists of various elastic fluids more or less lucid and transparent, and of which the lucid one is that which furnishes us with light.
		59	The manner in which I suppose the lucid fluid of the sun to be generated in its atmosphere may be better understood from an analogy drawn from the generation of clouds in our own atmosphere. [This analogy is stated.]
		60	That the emission of light must waste the sun is not a difficulty that can be opposed to our hypothesis.
		60	Many of the operations of nature are carried on in her great laboratory which we cannot comprehend, but now and then we see some of the tools with which she is at work. [The many telescopic comets may restore to the sun what is lost by the emission of light.]
		61	According to my theory a dark spot in the sun is a place in its atmosphere which happens to be free from luminous decompositions, and faculæ are more copious mixtures of such fluids as decompose each other.
		62	The penumbra which attends the spots being depressed more or less to about half way between the solid body of the sun and the upper part of the regions where luminous decompositions take place, must of course be fainter than other parts.
		62	The regions where the luminous solar clouds are formed, adding thereto the elevation of the faculæ, cannot be less than 1,843 miles nor much more than 2,765 miles.

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1795 85 62 We ought to compare these elevations, not to the clouds of our atmosphere, but to the elevation of the aurora borealis.

62 The density of the solar clouds though very great may not be exceedingly more so than that of the aurora.

62 The opaque body of the sun we know to be of great solidity, and we surmise it to be diversified with mountains and valleys.

63 This way of considering the sun removes the great dissimilarity between its condition and that of the other great bodies of the system. The sun then appears to be nothing else than a very eminent, large, and lucid planet * * * most probably also inhabited by beings whose organs are adapted to the peculiar circumstances of that vast globe.

63 The heat produced by the sun's rays on the earth is so considerable that it may be objected that the surface of the sun must be scorched up beyond all conception.

64 This objection answered by analogies with terrestrial circumstances.

65 I will now show that our moon is probably inhabited.

66 The moon is in many ways analogous to the earth, and to complete the analogy it is only needed that it should be inhabited. To this may be objected that we perceive no large seas there, that its atmosphere is extremely rare, that there is no rain, etc.

66 These objections considered.

67 Suppose an inhabitant of the moon who has not properly considered such analogical reasonings as might induce him to surmise that our earth is inhabited, to give it as his opinion that the use of the earth is to illuminate the moon, when direct daylight cannot be had, etc.

67 Suppose the inhabitants of the moons of *Jupiter*, *Saturn*, and [*Uranus*] to look upon their primary planets merely as so many attractive centers to keep together their orbits, etc., etc.

67 These considerations ought to make the inhabitants of the planets wiser than we have supposed those of their satellites to be. We surely ought not to say "the sun is merely an attractive center to us."

68 That stars are suns can hardly admit of a doubt. The sun turns on its axis; so do variable stars; most probably all stars. Stars have spots like the sun; in some stars we know these spots to be changeable.

68 Analogy may induce us to conclude that each of these stars is accompanied by a group of planets. If these suns themselves are primary planets we may see some thousands of them with our own eyes, and millions by the telescope, while the same analogy remains in regard to the planets which these suns may support.

69 The idea of suns or stars being *merely* the supporters of systems of planets is not to be admitted as a general one.

69 The stars in very compressed clusters are so close that even at a great distance of the cluster there will not be room for the crowding in of those planets for whose support these stars may be supposed to exist.

69 As an instance, I take clusters Nos. 26, 28, and 35 of the VI class, and also very close double stars.

70 Also, in some parts of the milky way the stars are so crowded that in 41 minutes of times no less than 258,000 stars passed through the field of my telescope [in R. A. $19^h\ 35^m$—$20^h\ 12^m$; N. P. D., 73° 54′].

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1795	85	71	It seems, therefore, upon the whole not improbable that in many cases stars are united in such close systems as not to leave much room for the orbits of planets or comets; and that consequently many stars, unless we would make them mere useless brilliant points, may themselves be lucid planets, perhaps unattended by satellites.
		71	*Postscript.* The following observations of the sun are added. They are decisive in regard to one of the conditions of the lucid matter of the sun. 1794, Nov. 26. The sun is mottled everywhere, equally at poles and equator. This is owing to inequalities in its surface.
		71	The lucid substance of the sun is neither a liquid nor an elastic fluid, as is evident from its not instantly filling up the cavities of the spots, etc. It exists, therefore, in the manner of lucid clouds swimming in the transparent atmosphere of the sun; or, rather, of luminous decompositions taking place within that atmosphere.
1795	85	347	*Description of a forty-foot reflecting telescope.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 11, 1795.
		347	When I resided at Bath I had long been acquainted with the theory of optics and mechanics and wanted only that experience so necessary in the practical part of these sciences. This I acquired by degrees at that place, where in my leisure hours by way of amusement I made several 2-foot, 5-foot, 7-foot, 10-foot and 20-foot Newtonian telescopes, besides others of the Gregorian form of 8, 12, 18 inches and 2, 3, 5 and 10 feet focal length.
		348	In this way I made not less than 200 7-foot, 150 more 10-foot, and about 80 20-foot mirrors, not to mention the Gregorian telescopes.
		348	The number of stands I invented for these telescopes it would not be easy to assign. My Newtonian stand was contrived about 1778.
		348	In 1781 I began to construct a 30-foot aërial reflector, and having made a stand for it I cast the mirror 36 inches in diameter, which was cracked in cooling. I cast it a second time, and the furnace which I had built in my house broke. Soon after, the *Georgian Planet* was discovered [and observations on this interrupted the making of new telescopes.]
		349	In 1783 I finished a very good 20-foot reflector, and in 1785 I began to construct the 40-foot.
		349	In the whole of the apparatus none but common workmen were employed, for I made drawings of every part of it and directed every person's labor, though sometimes there were not less than 40 employed at the same time. There was no interruption except my removal from Clay Hall to Slough.
		350	The 40-foot speculum was put into the tube and first used 1787, Feb. 19. The first mirror being too thin, etc., could not receive a good figure, and a second was cast 1788, Jan. 26, which cracked in cooling. It was recast Feb. 16, and on Oct. 24 it had a good figure and I observed *Saturn* with it; but not being satisfied I worked upon it till Aug. 27, 1789. Aug. 28, 1789, I discovered a sixth satellite of *Saturn*. I date the finishing of the telescope from that time.
		350	*Description of the telescope.* See Plates XXIV to XLII.
		350–365	The foundation and stand.
		365	The tube: it is 39 feet 4 inches long, 4 feet 10 inches diameter, made of iron.
		377	Motions of the telescope.

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1795 85 378 Finder and setting quadrant.

380 I have in 1789 many times taken up *Saturn* two or three hours before its meridian passage and kept it in view with the greatest facility till two or three hours after the passage, with a single assistant.

382 The method of observing is by what I have called the front view.

382 The observing chair is fastened to the instrument.

383 The aperture of the telescope is 4 feet.

384 In making sweeps several conveniences are required [as given].

385 A speaking pipe was led from the observer to the recorder, etc.

387 Right ascension apparatus.

390 Polar distance machine: the sidereal clock by SHELTON.

390 Polar distance piece [described].

396 In 1783, when I began my sweeps, no catalogue of stars in zones existed. I therefore gave a pattern to my indefatigable assistant, CAROLINA HERSCHEL, who brought all the British catalogue into zones of 1° each from 45 N. P. D. to the horizon, and put the right ascensions in time. This catalogue was afterwards completed to the pole in zones of 5°.

398 A zone clock described.

403 The construction of the great mirror is as in fig. 46. The metal is 49¼ inches in diameter; 48 inches are polished. Its thickness, which is equal throughout, is 3½ inches; its weight when cast was 2,118 lbs.

404 It is swung in a ring.

406 The surface is protected from damp by a tin cover.

409 Method of mounting the eye-pieces.

WM. HERSCHEL.

[Dated] Slough, near Windsor, May 18, 1795.

Plates.

408 Plate XXIV: General View: "To GEORGE THE THIRD, KING OF GREAT BRITAIN &c. This View of a Forty-Foot Telescope constructed under his Royal Patronage, is with permission, most humbly inscribed, by his Majesty's very devoted and Loyal Subject, and most grateful obedient Servant, William Herschel."

1796 86 133 *Additional observations on the Comet.* [1796, I.] By WILLIAM HERSCHEL, LL. D., F. R. S. [Read November 12, 1795.]

1796 86 166 *On the method of observing the changes that happen to the fixed stars; with some remarks on the stability of the Light of our Sun. To which is added a Catalogue of Comparative Brightness for ascertaining the Permanency of the Lustre of Stars.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read February 25, 1796.

166 The earliest observers noted the different brilliancy of stars and have classed them into magnitudes. Brightness and [apparent] size were taken as synonymous terms, and may still be used as such, notwithstanding the latter must be a consequence of the former.

166 If we suppose the stars to be about the size of our sun and at nearly an equal distance from us and from each other, those which form the first enclosure about us will appear brighter than the rest, and there can only be a small number of them.

166 This hypothesis is nearly confirmed by observation, as may be seen by looking over a globe and applying a pair of compasses opened to 60°. Eleven pairs of 1st mag. stars are about 60° apart.

167 Eight other pairs are near enough to 60° to support this hypothesis.

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1796 86 167 A second layer of stars will be more extensive, etc., etc.

168 The hypothesis of an equality and an equal distribution of stars is too far from being strictly true to be laid down as an unerring guide.

168 The stars of the 1st and 2d class, scrupulously examined, prove that we must admit them to be either of different sizes or placed at different distances. Both varieties undoubtedly take place.

168 Thus it appears that in the classification of stars into magnitudes there is either no natural standard or none that can be satisfactory.

169 If any dependence could be placed upon the method of magnitudes, it would follow that certain of FLAMSTEED'S stars had undergone a change in their lustre. [Examples given.]

170 FLAMSTEED did not compare the stars to each other, but referred each of them separately to its own imaginary standard.

A short inquiry into the confidence to be given to the method of magnitudes may be of considerable use.

170 In FLAMSTEED'S observations an error of 1^m in the brighter classes and $1\frac{1}{2}^m$ in the fainter would hardly deserve attention.

171 In comparing the observations of different astronomers larger errors may be expected.

172 Example. From FLAMSTEED'S and LACAILLE'S observations of β *Leonis* we may conclude that this star is now less brilliant than formerly.

173 I place each star, instead of giving its magnitude, into a short series [sequence] constructed upon the order of brightness of the nearest proper stars.

174 The Greek letters now affixed to the names of stars do not point out their order of brightness, except for the few brightest stars of each constellation. [Examples.]

175 A doubt may arise whether any succession of brightness might be argued from the very first, second, or third letters of the alphabet, when we find them now arranged thus, as β α *Cassiopeæ*, β α *Cancri*, γ β *Aquilæ*, etc.

177 LALANDE, PIGOTT, and GOODERICKE have used the method I propose in special cases.

178 Simple as my method is in principle, it is very laborious in its progress. I began to use it 14 years ago.

178 My first design was to draw each whole constellation into one series. Accordingly I began, July 16, 1781, to arrange the stars in *Ophiuchus*, thus: α, β, δ, ζ, η, κ, γ, ε. The defect of this arrangement was that we do not always have a proper connection of the steps of the series; the intervals being too great in some cases, too small in others.

178 To get over these difficulties I marked the stars by degrees, three in a magnitude 1′, 1″, 1‴; 2′, 2″, 2‴, etc., as "May 12, 1783; order of the stars in *Boötis* "α 1′, ε 2″, η 2‴, γ β δ 3′, etc"

179 Difficulties with this plan.

180 Other methods tried.

181 The method finally adopted explained. [The method of sequences.]

183 Difficulties in carrying out the method stated.

184 These observations are of importance, as will appear when we remember the great number of alterations of stars which have certainly happened within two centuries.

185 Who would not wish to know the permanency of the lustre of our Sun? If it be allowed to admit the similarity of stars with our sun,

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how necessary will it be to take notice of the fate of our neighboring *suns* in order to guess at that of our own. That *star* which we call the *Sun* may to-morrow begin to undergo a gradual decay of brightness, like *β Leonis*, *α Ceti*, *α Draconis*, *δ Ursæ Majoris*, and many others that will be mentioned in my catalogues.

1796 86 186 It may suddenly increase like the wonderful star in the back of *Cassiopea's* chair, or gradually come on like *β Geminorum*, *β Ceti*, *ζ Sagittarii*, etc.; or it may turn into a periodical star of 25 days' duration, as *Algol* is one of 3 days, *δ Cephei* of 5 days, etc.

186 Perhaps the easiest way of accounting for past changes in our climates is to surmise that our sun has been formerly sometimes more or sometimes less bright than now.

187 A method of ascertaining the quantity or intenseness of solar light might be contrived. Perhaps the thermometer alone might be sufficient.

187 *Introductory Remarks and Explanations of the Arrangement and Characters used in the following Catalogue.*

This *first* catalogue contains 9 constellations; the rest will follow.

190 All the observations have been made in very fine nights when there was no suspicion of any whitish haziness.

191 All observations upon stars of any considerable magnitude have been made with the naked eye.

191 Wherever I have used magnitudes I have adopted FLAMSTEED'S scale.

192 From the numerous differences we have reason to suspect many changes in the lustre of stars since FLAMSTEED'S time.

192 Summary of differences with FLAMSTEED.

194 I. *Catalogue of the comparative brightness of the Stars.*

212 *Notes.* These contain errata in FLAMSTEED'S atlas and ca alogue.

226 WM. HERSCHEL.

[Dated] Slough, near Windsor, Jan. 1, 1796.

1796 86 452 *On the periodical star α Herculis; with remarks tending to establish the rotatory motion of the Stars on their axes. To which is added a second catalogue of the comparative Brightness of the stars.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 9, 1796.

452 In my first catalogue I announced *α Herculis* as a periodical star. It has been compared with several standard stars but chiefly with *κ Ophiuchi.*

453 Table of the variation of light observed in *α* (Fl. 64) *Herculis*, compared to *κ* (Fl. 27) *Ophiuchi.*

454 The period is about 60 days and a quarter. Greater accuracy can only be obtained by future observations.

455 *On the Rotatory motion of the Stars on their Axes.*

455 We ought not to be satisfied with enrolling the discovery of one more periodical star among the list of facts we are acquainted with; for this would indeed be of no great consequence.

455 Darker spots on the surface of stars will account for all the phenomena of periodic stars so satisfactorily that we certainly need not look out for any other cause. The objections which may be made are: the periods in *Algol*, *β Lyræ*, *δ Cephei*, and *η Antinoi* are short 3, 5, 6, and 7, etc., days; those of *o Ceti*, the star in *Hydra* and in *Cygnus* are long; 331, 394, and 497 days.

456 Hitherto we have had but 7 periodical stars [some of very short, some

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of very long periods]; the discovery of α *Herculis* as a periodical star with a period of 60 days supplies a link in the chain and removes the objection that arose from the vacancy.

1796 86 456 Another instance of slow rotation is the 5th satellite of *Saturn* [*Japetus*], which revolves on its axis in 79 days.

457 The rotations of the sun, moon, and some of the planets are known by their spots; [*Japetus*] is too small and too distant to allow its spots to be observed. But what we can no longer perceive we can now supply by rational arguments. The change in the light of the satellite proves the rotation; the rotation proves the existence of the spots. A still more extended similarity between the sun and the stars offers itself, by the spots which must also be admitted to take place.

457 There are reasons to surmise that 34 *Cygni* is a periodical star of 18 years' return [see *Phil. Trans.*, 1786, p. 201].

458 When the biography of the stars, if I may be allowed the expression, is arrived to more perfection, we may then possibly not only be still more assured of their rotatory motion, but also perceive that they have other movements, such as nutations of their axes, etc.

458 *Memorandum relating to the following Catalogue.* I find the magnitudes of FLAMSTEED so inconsistent that I shall not continue to note the deviations between my observations and his.

459 II. *Catalogue of the comparative brightness of the Stars.*

477 *Notes.*

WM. HERSCHEL.

[Dated] Slough near Windsor, June 1, 1796.

1797 87 293 *A Third Catalogue of the comparative Brightness of the Stars; with an introductory account of an Index to* Mr. FLAMSTEED'S *Observations of the Fixed Stars contained in the second volume of the Historia Cœlestis. To which are added several useful results derived from that Index.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read May 18, 1797.

293 In my earliest reviews of the heavens I found many of the stars of the British Catalogue missing, and took it for granted that they were lost. The deviation of many stars from the magnitudes there given I looked upon as changes in the lustre of the stars. I therefore wished to be able to refer to the original observations upon which the Catalogue was founded, and recommended to my sister the arduous task.

294 She began the work about 20 months ago, and has lately finished it.

294 Description of the manner of making the index.

295 Examples of its use.

296 General results to be obtained from an inspection of the index [with regard to FLAMSTEED'S errors].

297 *Additional notes to the stars in the First Catalogue of the comparative brightness of the Stars.*

301 *Same* for the *Second Catalogue.*

307 III. *Catalogue of the comparative brightness of the Stars.*

321 *Notes.*

WM. HERSCHEL.

324 [*Dated*] Slough, near Windsor, April 12, 1797.

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1797	87	332	*Observations of the changeable Brightness of the Satellites of Jupiter, and of the Variation in their apparent Magnitudes; with a Determination of the Time of their rotatory Motions on their Axes. To which is added a Measure of the Diameter of the Second Satellite, and an Estimate of the comparative size of all the Four.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 1, 1797.
1797	87	332	I have, when other pursuits would permit, attended to every circumstance that could forward the discovery of the rotation of the secondary planets. Since I have determined by observation that *Japetus* rotates according to the law obeyed by our moon, it seems natural to conclude that all the secondary planets do the same; consequently, a few good observations that coincide with this theory will go a good way towards confirming it.
		333	I also desired to examine the nature and construction of the satellites. Here phenomena occurred that may be thought remarkable and perhaps contradictory. So far from attempting to lessen the force of such animadversions, I shall be the first to point out difficulties in order that future observations may be made to resolve them.
		334	OBSERVATIONS: *A remarkable Conjunction of two satellites of Jupiter.* II and III cannot be separated with a power of 350 on a 7-foot reflector.
		334	*Intenseness of Light and Color of the Satellites.* I is of a very intense, bright, white, and shining light. It is brighter than II or IV (not larger). IV is inclining to red. It is nearly as bright as II. II is of a dull ash color. III is very white.
		335	*Brightness and diameter distinguished.*
		335	*Diameter of the second Satellite by entering on the Disc of the Planet.*
		339	The *Brightness of the Satellites compared to the Belts and Disk of the Planet.*
		339–342	[Estimates of comparative magnitudes of I, II, III, IV.]
		342	Before we draw any conclusions from these observations, we ought to take notice of the many causes of deception, etc. The method of comparing the brightness is not subject to so great errors as estimating this in terms of an ideal standard. But the situation of the satellites with respect to the planet introduces a new source of error.
		343	Objections to both low and high magnifiers.
		344	It appears that considerable changes take place in the brightness of the satellites, and also a change in their apparent magnitude.
		344	The first fact proves that the satellites have a rotatory motion upon their axes of the same duration with their revolutions about the primary planet. The second either shows that the bodies of the satellites are not spherical, or that some parts of the discs reflect hardly any light.
		345	Discussion of the observations to show that the satellites revolve on their axes in the same time that they revolve about the planet. The observations extend from 1794, July 19, to 1796, November 3.
		346	*Table of the positions of the four satellites at the time of the observations.*
		347	Method of reduction.
		349	Summary of the observations relating to the color of the satellites. I is white, but sometimes more intensely so than others. II is white, bluish, and ash-colored.
		350	III is always white, but the color is of different intensity in different situations.

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			IV is dusky, dingy, inclining to orange, reddish, and ruddy at different times; and these tints may induce us to surmise that this satellite has a considerable atmosphere.
1797	87	350	The diameter of the second satellite is 0''.87 by 1 obs.
		351	III is considerably larger than any of the rest; I is a little larger than II, and nearly of the size of IV; II is a little smaller than I and IV, or the smallest of all. WM. HERSCHEL.
			[Dated] Slough, near Windsor, April 30, 1797.
1798	88	47	*On the discovery of four additional satellites of the Georgium Sidus. The retrograde motion of its old Satellites announced, and the cause of their Disappearance at certain distances from the Planet explained.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read December 14, 1797.
		47	I have lately recomputed my observations of the satellites of [*Uranus*] with improved tables from 1787 to now. I laid down a set of theorems relating to the motions of these satellites; I calculated tables and devised means for checking the computations.
		48	I here announce that the motion of the Georgian satellites is retrograde.
		48	From my miscellaneous observations, the existence of four additional satellites will be proved; the observations which tend to ascertain the existence of rings to the planet not being satisfactorily supported, this surmise will be given up, or left till superior instruments are provided.
		48	Observations of stars near the planet are given under the head *Reports*, and of the new satellites under the head *Observations*.
		49	*Investigation of additional satellites.*
		58	*Arguments upon the Reports and Observations.*
			An interior satellite. [The observations described.]
		62	*An intermediate satellite.* [The observations described.]
		63	*An exterior satellite.* [The observations described.]
		64	*The most distant satellite.* [The observations described.]
		66	The arrangement of the satellites together will be thus: First satellite, the interior one of Jan. 18, 1790. Second satellite, the nearest old one of Jan. 11, 1787. Third satellite, the intermediate one of Mar. 26, 1794. Fourth satellite, the farthest old one of Jan. 11, 1787. Fifth satellite, the exterior one of Feb. 9, 1790. Sixth satellite, the most distant one of Feb. 28, 1794.
		67	*Observations and reports tending to the discovery of one or more rings of the Georgian Planet and the flattening of its Polar Regions.*
		69	*Remarks upon the foregoing observations.*
		70	The observation of the 26th Feb., 1792, seems to be very decisive against the existence of a ring, etc., and I venture to affirm that the planet has no ring in the least resembling those of *Saturn*.
		70	The flattening of the poles of the planet seems to be sufficiently ascertained.
		71	This being admitted, we may conclude that the *Georgian Planet* also has a rotation on its axis of a considerable degree of velocity.
		71	*Reports and observations relating to the light and size of the Georgian satellites, and to their vanishing at certain distances from the Planet.*
		73	*Remarks on the foregoing observations.*
		73	Small stars near the planet lose much of their lustre.

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1798 88 74 The satellites become regularly invisible at certain distances from the planet.

76 The first satellite [*Titania*] usually vanishes at 18″.

The second satellite [*Oberon*] usually vanishes at 20″.

In uncommon and beautiful nights the *first* has once been seen at 13″.8 and the 2d at 17″.3.

77 A dense atmosphere to the planet would account for this if it were not that the satellites are lost as well in the nearest half of their orbits as in the farthest. A satellite cannot be obscured by an atmosphere that is behind it.

77 The light of *Jupiter* and *Saturn* is diffused for several minutes [*of arc*] all around them. Their satellites are bright, and having much light to lose they comparatively lose but little. [*Uranus*] is very faint; its satellites are very nearly the dimmest objects that can be seen in the heavens, so that they cannot bear any considerable diminution of their light without becoming invisible.

78 The distances at which the satellites vanish will show their relative brightness. The first satellite [*Titania*] is rather brighter than the second [*Oberon*]. The interior satellite cannot be much inferior in brightness to these.

78 *Periodical Revolutions of the New Satellites.*

[Dated] Slough, near Windsor, September 1, 1797.

1799 89 121 *A Fourth Catalogue of the Comparative Brightness of the Stars.* By William Herschel, LL. D., F. R. S. Read February 21, 1799.

121 *Catalogue.*

138 *Notes.*

[Dated] Slough near Windsor, Jan. 28, 1799.

1800 90 49 *On the power of penetrating into Space by Telescopes; with a comparative Determination of the Extent of that Power in natural Vision, and in Telescopes of various Sizes and Constructions; illustrated by select observations.* By William Herschel, LL. D., F. R. S. Read November 21, 1799.

49 The power of penetrating into space by telescopes is very different from magnifying power, and ought to be considered separately.

49 Luminous bodies as here defined are such as throw out light, whatever may be the cause of it, including those that shine by reflection only, and we may distinguish the class of self-luminous bodies when it is necessary.

50 The question will arise whether luminous bodies scatter light in all directions equally; but until we know more of the powers that emit and reflect light we shall probably remain ignorant on this head.

50 What I mean to say relates only to the physical points into which we may suppose the surfaces of luminous bodies to be divided. When we consider their whole construction the question assumes another form.

50 We know from experience that light, flame, and luminous gases are penetrable to the rays of light.

50 [Foot-note.] An experiment given to prove this.

51 It follows therefore that every part of the sun's disc cannot appear equally luminous to a given observer on account of the unequal depth of its atmosphere. (See *Phil. Trans.*, 1795, p. 46.)

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1800	90	51	The greatest inequalities in the brightness of luminous bodies will be owing to their natural texture.
		51	Brightness, I ascribe to bodies that throw out light, and those that throw out most are the brightest.
		51	Let the whole quantity of light thrown out by a luminous body be, L; suppose the surface of this body to be composed of N luminous physical points. Let C stand for the mean copiousness of light thrown out from all the physical points of a luminous object. Let *c* express the copiousness of emitting light of any number of physical points that agree in this respect, and let their number be *n*; similarly I define c^1 and n^1 for another set of points, and so on. Then $L = cn + c^1n^1 + c^2n^2 +$ etc., and $L \div N = C$.
		52	An objection to this answered.
		52	The brightness of an object is truly defined by CN. The brightness arising from the great value of C may be called the intrinsic brightness; that from the great value of N the aggregate brightness; the absolute brightness is in all cases CN.
		53	In finding an expression for the appearance of luminous objects at any assigned distance we must leave out of account every part of CN which is not applied for the purposes of vision. L representing the whole light thrown out by CN, let *l* be that part of it used in vision either by the eye or the telescope.
		53	The equation of light, in this sense, is $CN = l$.
		53	The expression for its quantity at the distance of the observer D will be $l \div D^2$.
		53	In natural vision *l* undergoes a considerable change by the opening or contracting of the pupil of the eye.
		53	In some experiments on light made at Bath in 1780 I [noticed the increased power of vision after staying some time in a dark room].
		53	The opening of the iris is probably not the only cause of seeing better after remaining long in the dark, but the tranquillity of the retina may render it more fit to receive impressions.
		54	This is supported by telescopic vision, for in my sweeps of 4, 5, or 6 hours' duration my eye became so sensitive that when a star of the 3d magnitude came towards the field of view I had to withdraw my eye in order not to injure the delicacy of vision. The opening of the iris was not the cause, as the diameter of the optic pencil was no more than 0.12 inch.
		54	With the 40-foot telescope the appearance of *Sirius* announced itself like the dawn of the morning till this brilliant star at last entered the field of the telescope with all the splendor of the rising sun, and forced me to take my eye from that beautiful sight.
		55	I found the eye, coming from the light, required nearly 20 minutes before it could see delicate objects, and that the view of a star of the 2d or 3d magnitude would so disorder it that nearly the same time was required to reëstablish its tranquillity.
		55	If *a* is the opening of the iris and A the aperture of the telescope $\frac{a^2L}{D^2}$ is the light admitted by the eye, and $\frac{A^2L}{D^2}$ will be that admitted by the telescope.
		55	Whenever the pencil of light from the telescope is larger than the aperture of the pupil, light is lost. If *m* be the magnifying power, $A \div m$ ought not to exceed *a*.

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1800	90	55	Objection to the foregoing. It being proved that an object is equally bright at all distances, it may be urged that in a telescope the different distance of stars can be of no account with regard to their brightness, and that we must consequently be able to see stars which are many thousands of times farther than *Sirius* from us.
		56	The origin of such objections is in want of distinction in the two sorts of brightness, which have been discriminated by intrinsic and absolute brightness.
		56	The demonstrations of opticians with regard to what I call *intrinsic* brightness, will not oppose what I affirm of *absolute* brightness.
		57	Though the sun, to an observer on *Saturn*, must be as bright as it is here on the earth, it cannot be meant that an inhabitant standing on the planet *Saturn* and looking at the sun should *absolutely* receive as much light from it as one on earth receives when he sees it.
		57	The picture of the sun on the retina of the Saturnian observer is as *intensely* illuminated as that on the retina of the terrestrial astronomer, but it should be remembered that the sun on *Saturn* appears to be a hundred times less than on the earth; and that consequently, though it may there be *intrinsically* as bright, it must here be *absolutely* an hundred times brighter.
		57	This reasoning is entirely applicable to the stars; and the light we can receive from the stars is truly expressed by $\frac{a^2 l}{D^2}$.
		58	Hence I am authorized to conclude that stars cannot be seen by the naked eye when they are more than seven or eight times farther from us than *Sirius*, and that they become, comparatively speaking, very soon invisible *with our best instruments*.
		58	With respect to the naked eye, the power of penetrating into space is limited. Among reflecting luminous objects our penetrating powers are sufficiently ascertained. An object seen by reflected light at a greater distance than the *Georgian Planet*, it has never been allowed us to perceive.
		59	The range of natural vision with self-luminous objects is incomparably more extended, but less accurately to be ascertained.
		59	The general supposition is admitted that stars, at least those which seem to be promiscuously scattered, are probably one with another of a certain magnitude.
		59	[Foot-note.] The *Phil. Trans.* for the year 1796, page 166, 167, 168 is referred to for support of this assumption.
		60	The difference in brightness between *Sirius*, *Arcturus*, *α Cygni*, and *β Tauri*, does not seem to alter the dimensions of the iris; *a*, therefore, becomes a given quantity and may be left out.
		61	Admitting that the latter of these stars are probably at double the distance of the former, we can have no other guide to lead us a third step than the before-mentioned hypothesis; in consequence of which it is probable that stars of the third magnitude may be placed about three times as far from us as those of the first.
		61	Our third step forward into space may therefore very properly be said to fall on the pole star, on *γ Cygni*, *ε Boötis*, and all those of the same order.
		62	The difference between these and the stars of the preceding order is much less striking than that between the stars of the first and second magnitudes. So the calculated ratio of the brightness of a star

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of the sixth magnitude to that of one of the seventh, is but little more than $1\frac{1}{4}$ to 1.

1800 90 62 The faintness of the stars of the 7th magnitude gives us little room to believe that we can penetrate much farther into space with objects of no greater brightness than stars.

63 I think, from the faintness of the stars of the 7th magnitude, and from the foregoing considerations, we are authorized to conclude that no star, eight, nine, or at most ten times as far from us as *Sirius*, can possibly be perceived by the natural eye.

63 Where the light of single stars falls short, however, the united lustre of sidereal systems will still be perceived. We easily see the united lustre of the stars in the sword-handle of *Perseus*, though the light of no one of the single stars could have affected the unassisted eye.

64 Perhaps, among the farthest objects that can make an impression on the eye, when not assisted by telescopes, may be reckoned the nebula in the girdle of *Andromeda* discovered by SIMON MARIUS in 1612.

64 It has been shown that brightness or light is to the naked eye truly represented by $\frac{a^2l}{D^2}$; in a telescope, therefore, the light admitted will be expressed by $\frac{A^2l}{D^2}$. Hence it would follow that the artificial power of *penetrating into space* should be to the natural one as A to a. But this proportion must be corrected by the practical deficiency in light reflected and transmitted.

65 As the result of many experiments with plane mirrors, polished like my large ones, and of the same composition of metal, I find we shall have, in a telescope of my construction, with one reflection, 63,796 rays, out of 100,000 come to the eye. In the Newtonian form, with a single eye-lens, 42,901; and, with a double eye-glass, 40,681 will remain for vision.

65 Since the brightness of luminous objects is inversely as the squares of the distances, it follows that the penetrating power must be as the square roots of the light received by the eye.

66 In natural vision, therefore, this power is truly expressed by $\sqrt{a^2l}$, and since we have now also obtained a proper correction x, we must apply it to the incident light with telescopes.

66 In the Newtonian and other constructions where two specula are used there will also be some loss of light on account of the interposition of the small speculum; therefore, putting b for its diameter, we have $\overline{A^2-b^2}$ for the real incident light. This being corrected as above, will give the general expression $\sqrt{xl \times \overline{A^2-b^2}}$ for the same power in telescopes.

66 Then, if we put natural light $l = 1$, and divide by a, we have the general form $\frac{\sqrt{x.\overline{A^2-b^2}}}{a}$ for the penetrating power of all sorts of telescopes, compared to that of the natural eye as a standard.

66 In the following investigation we shall suppose $a =$ two-tenths of an inch.

67 "In the year 1776, when I had erected a telescope of 20 foot focal length, of the Newtonian construction, one of its effects by trial was, that when towards evening, on account of darkness, the natural eye could not penetrate far into space, the telescope possessed

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that power sufficiently to shew by the dial of a distant church steeple what o'clock it was, notwithstanding the naked eye could no longer see the steeple itself. Here I only speak of the penetrating power; for though it might require magnifying power to see the figures on the dial, it could require none to see the steeple."

The space-penetrating power of this telescope was 38.99.

1800 90 68–81 [Dimensions of various telescopes used by HERSCHEL, and their calculated space-penetrating powers are given, together with a large number of examples quoted from his note-books illustrative of the relations of magnifying and space-penetrating powers.]

82 Comparison of the space-penetrating power of 20-foot telescope calculated according to the principles developed in this paper with that deduced from observation, as given in *Phil. Trans.*, vol. 75, p. 247, 248. A substantial agreement leads to the conclusion that no single star above 489.551, or at most 612 times as far as *Sirius*, can any longer be seen in this telescope.

83 The space-penetrating power of the large reflector was 192; admitting that stars of the 7th magnitude are visible to the unassisted eye, this telescope would show stars of the 1,342d magnitude. Therefore, a cluster of 5,000 stars might be seen by the 40-foot reflector at a distance at least 300,000 times that of the nearest fixed star.

84–85 The calculated time necessary to sweep the whole heavens with the 40-foot telescope, assuming 100 hours of observing time in the year as the most probable deduction from experience, is 812 years.

[Dated] Slough, near Windsor, June 20, 1799.

1800 90 255 *Investigation of the Powers of the prismatic Colours to heat and illuminate Objects; with remarks that prove the different Refrangibility of radiant Heat. To which is added an Inquiry into the Method of viewing the Sun advantageously with Telescopes of large Apertures and high magnifying Powers.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read March 27, 1800.

255 "It is sometimes of great use in natural philosophy to doubt of things that are commonly taken for granted; especially as the means of resolving any doubt, when once it is entertained, are often within our reach.

256 "In a variety of experiments I have occasionally made relating to the method of viewing the sun, with large telescopes, to the best advantage, I used various combinations of differently coloured darkening glasses. What appeared remarkable was that when I used some of them I felt a sensation of heat, though I had but little light; while others gave me much light, with scarce any sensation of heat. Now, as in these different combinations the sun's image was also differently coloured, it occurred to me that the prismatic rays might have the power of heating bodies very unequally distributed among them; and as I judged it right in this respect to entertain a doubt, it appeared equally proper to admit the same with regard to light. If certain colours should be more apt to occasion heat, others might, on the contrary, be more fit for vision, by possessing a superior illuminating power. At all events, it would be proper to recur to experiments for a decision."

256–260 Eight experiments to test heating power of red, green, and violet regions of the prismatic spectrum.

261 As a result, we have the proportion of the rising of the thermometer in red to that in green as more than $2\frac{1}{4}$ to 1; in red to violet about $3\frac{1}{4}$ to 1.

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1800 90 262 *Experiments on the illuminating Power of coloured Rays.*

262–270 Ten experiments on the visibility of objects illuminated by differently coloured light.

268 "The maximum of illumination lies in the brightest yellow or palest green."

270 "May not the chemical properties of the prismatic colours be as different as those which relate to light and heat? Adequate methods
271 for an investigation of them may easily be found; and we cannot too minutely enter into an analysis of light, which is the most subtle of all the active principles that are concerned in the mechanism of the operations of nature."

Radiant Heat is of different Refrangibility.

"I must now remark that my foregoing experiments ascertain beyond a doubt that radiant heat, as well as light, whether they be the same or different agents, is not only refrangible, but is also subject
272 to the laws of dispersion arising from its different refrangibility; and, as this subject is new, I may be permitted to dwell a few moments upon it. The prism refracts radiant heat, so as to separate that which is less efficacious from that which is more so. The whole quantity of radiant heat contained in a sunbeam, if this different refrangibility did not exist, must inevitably fall uniformly on a space equal to the area of the prism; and if radiant heat were not refrangible at all, it would fall upon an equal space in the place where the shadow of the prism, when covered, may be seen. But, neither of these events taking place, it is evident that radiant heat is subject to the laws of refraction, and also to those of the different refrangibility of light. May not this lead us to surmise that radiant heat consists of particles of light of a certain range of momenta, and which range may extend a little farther on each side of refrangibility than that of light? We have shewn that in a gradual exposure of the thermometer to the rays of the prismatic spectrum, beginning from the violet, we come to the maximum of light long before we come to that of heat, which lies at the other extreme. By several experiments, which time will not allow me now to report, it appears that the maximum of illumination has little more than half the heat of the full red rays; and, from other experiments, I likewise concluded that the full red falls still short of the maximum of heat, which perhaps lies even a little beyond visible refraction. In this case, radiant heat will at least partly, if not chiefly, consist, if I may be permitted the expression, of invisible light; that is to say, of rays coming from the sun, that have such a momentum as to be unfit for vision. And, admitting, as is highly probable, that the organs of sight are only adapted to receive im-
273 pressions from particles of a certain momentum, it explains why the maximum of illumination should be in the middle of the refrangible rays, as those which have greater or less momenta are likely to become equally unfit for impressions of sight. Whereas, in radiant heat, there may be no such limitation to the momentum of its particles. From the powerful effects of a burning lens, however, we gather the information that the momentum of terrestrial radiant heat is not likely to exceed that of the sun, and that, consequently, the refrangibility of *calorific* rays cannot extend much beyond that of *colourific* light. Hence, we may also infer that the

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			invisible heat of red-hot iron, gradually cooled till it ceases to shine, has the momentum of the invisible rays which, in the solar spectrum viewed by daylight, go to the confines of the red; and this will afford an easy solution of the reflection of invisible heat by concave mirrors."
1800	90	273	*Application of the Result of the foregoing observations to the Method of viewing the Sun advantageously with Telescopes of large Apertures and high magnifying Powers.*
		274	Relation of experience which led to investigation.
		275–276	Experiments on the absorption of various media.
		277	*Telescopic Experiments.*
		277–282	Description of twenty-seven experiments to determine the best form of sun-glass for telescopes.
		283	Certain precautions to be observed in using telescopes on the sun.
			[Dated] Slough, near Windsor, March 8, 1800.
1800	90	284	*Experiments on the Refrangibility of the invisible Rays of the Sun.* By William Herschel, LL. D., F. R. S. Read April 24, 1800.
		284	Description of method. Three sensitive thermometers were placed upon a small stand upon which a spectrum of the sunlight was caused to fall.
		285	Report of first experiment. A thermometer ½ inch beyond limit of visible red rose 6½ degrees in 10 minutes.
		286	Report of second experiment. As a result it was "evident that there was a refraction of rays coming from the sun, which, though not fit for vision, were yet highly invested with a power of occasioning heat."
		287–288	Experiments at the violet end of the spectrum.
			"From these last experiments I was now sufficiently persuaded that no rays which might fall beyond the violet could have any perceptible power, either of illuminating or of heating; and that both these powers continued together throughout the prismatic spectrum, and ended where the faintest violet vanishes."
		289–290	Experiments to determine the situation of the maximum of the heating power.
		291	"The 5th and 6th experiments show, that the power of heating is extended to the utmost limits of the visible violet rays, but not beyond them, and that it is gradually impaired as the rays grow more refrangible.
			"The four last experiments prove, that the maximum of the heating power is vested among the invisible rays; and is probably not less than half an inch beyond the last visible ones, when projected in the manner before mentioned. The same experiments also show, that the sun's invisible rays, in their less refrangible state, and considerably beyond the maximum, still exert a heating power fully equal to that of red-coloured light; and that, consequently, if we may infer the quantity of the efficient from the effect produced, the invisible rays of the sun probably far exceed the visible ones in number.
			"To conclude, if we call *light*, those rays which illuminate objects, and *radiant heat*, those which heat bodies, it may be inquired whether light be essentially different from radiant heat? In answer to which I would suggest, that we are not allowed, by the rules of philosophizing, to admit two different causes to explain certain effects, if

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they may be accounted for by one. A beam of radiant heat, emanating from the sun, consists of rays that are differently refrangible. The range of their extent, when dispersed by a prism, begins at violet-coloured light, where they are most refracted and have the least efficacy. We have traced these calorific rays throughout the whole extent of the prismatic spectrum; and found their power increasing, while their refrangibility was lessened, as far as to the
1800 90 292 confines of red-coloured light. But their diminishing refrangibility and increasing power did not stop here; for we have pursued them a considerable way beyond the *prismatic spectrum*, into an invisible state, still exerting their increasing energy, with a decrease of refrangibility, up to the maximum of their power; and have also traced them to that state where, though still refracted, their energy, on account, we may suppose, of their now failing density, decreased pretty fast; after which the invisible *thermometrical spectrum*, if I may so call it, soon vanished.

"If this be a true account of solar heat, for the support of which I appeal to my experiments, it remains only for us to admit that such of the rays of the sun as have the refrangibility of those which are contained in the prismatic spectrum by the construction of the organs of sight are admitted under the appearance of light and colours; and that the rest, being stopped in the coats and humours of the eye, act upon them, as they are known to do upon all the other parts of our body, by occasioning a sensation of heat."

Explanation of Plate XI, in which is given a view of the apparatus.

[Dated] Slough, near Windsor, March 17, 1800.

1800 90 293 *Experiments on the solar and on the terrestrial Rays that occasion Heat; with a comparative view of the Laws to which Light and Heat, or rather the Rays which occasion them, are subject, in order to determine whether they are the same or different.* By WILLIAM HERSCHEL, LL. D., F. R. S. Part I. Read May 15, 1800.

"The word heat, in its common acceptation, denotes a certain sensation well known to every person. The cause of this sensation, to avoid ambiguity, ought to have been distinguished by a name different from that which is used to point out its effect. Various authors, indeed, who have treated on the subject of heat, have occasionally added certain terms to distinguish their conceptions, such as latent, absolute, specific, sensible heat, while others have adopted the new expressions of caloric and the matter of heat. None of these descriptive appellations, however, would have completely answered my purpose. I might, as in the preceding papers, have used the name radiant heat, which has been introduced by a celebrated author, and which certainly is not very different from the expressions I have now adopted; but by calling the subject of my researches the rays that occasion heat I cannot be misunderstood as meaning that those rays themselves are heat, nor do I in any respect engage myself to show in what manner they produce heat.

"From what has been said it follows that any objections that may be alleged from the supposed agency of heat in other circum-
294 stances than in its state of radiance or heat-making rays cannot be admitted against my experiments. For, notwithstanding I may be inclined to believe that all phenomena in which heat is concerned, such as the expansion of bodies, fluidity, congelation, fer-

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mentation, friction, etc., as well as heat in its various states of being, latent, specific, absolute, or sensible, may be explained on the principle of heat-making rays, and vibrations occasioned by them in the parts of bodies; yet this is not intended at present to be any part of what I shall endeavor to establish.

"I must also remark that in using the word rays I do not mean to oppose, much less to countenance, the opinion of those philosophers who still believe that light itself comes to us from the sun, not by rays, but by the supposed vibrations of an elastic ether, everywhere diffused throughout space. I only claim the same privilege for the rays that occasion heat which they are willing to allow to those that illuminate objects. For, in what manner soever this radiance may be effected, it will be fully proved hereafter that the evidence, either for rays or for vibrations which occasion heat, stands on the same foundation on which the radiance of the illuminating principle, light, is built."

"We shall begin with the heat of luminous bodies in general, such as, in the first place, we have it directly from the sun; and as, in the second, we may obtain it from terrestrial flames, such as torches, candles, lamps, blue-lights, etc.

300 90 295 "Our next division comprehends the heat of coloured radiants. This we obtain, in the first place, from the sun, by separating its rays in a prism; and, in the second, by having recourse to culinary fires, openly exposed.

"The third division relates to heat obtained from radiants, where neither light nor colour in the rays can be perceived. This, as I have shown, is to be had, in the first place, directly from the sun, by means of a prism applied to its rays; and, in the second, we may have it from fires inclosed in stoves, and from red-hot iron cooled till it can no longer be seen in the dark.

"Besides the arrangement in the order of my experiments which would arise from this division, we have another subject to consider. For, since the chief design of this paper is to give a comparative view of the operations that may be performed on the rays that occasion heat, and of those which we already know to have been effected on the rays that occasion light, it will be necessary to take a short review of the latter. I shall merely select such facts as not only are perfectly well known, but especially such as will answer the intention of my comparative view, and arrange them in the following order: 1. Light, both solar and terrestrial, is a sensation occasioned by rays emanating from luminous bodies, which have a power of illuminating objects; and, according to circumstances, of making them appear of various colours. 2. These rays are subject to the laws of reflection. 3. They are also subject to the laws of refrac-
296 tion. 4. They are of different refrangibility. 5. They are liable to be stopped, in certain proportions, when transmitted through diaphanous bodies. 6. They are liable to be scattered on rough surfaces. 7. They have hitherto been supposed to have a power of heating bodies; but this remains to be examined.

"The similar propositions relating to heat, which are intended to be proved in this paper, will stand as follows: 1. Heat, both solar and terrestrial, is a sensation occasioned by rays emanating from candent substances, which have a power of heating bodies. 2. These rays

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are subject to the laws of reflection. 3. They are also subject to the laws of reflection. 4. They are of different refrangibility. 5. They are liable to be stopped, in certain proportions, when transmitted through diaphanous bodies. 6. They are liable to be scattered on rough surfaces. 7. They may be supposed, when in a certain state of energy, to have a power of illuminating objects; but this remains to be examined."

1800 90 297 1st Experiment. *Reflection of the Heat of the Sun.*

A thermometer was exposed at the eye end of a ten-feet Newtonian telescope. The rays, after three regular reflections, caused the thermometer to rise 58 degrees. The experiment cannot ascertain whether these rays were those of light or not.

2d Experiment. *Reflection of the Heat of a Candle.*

The ball of a thermometer, placed in the secondary focus of a steel mirror, received 3¼ degrees of heat in five minutes.

298 3d Experiment. *Reflection of the Heat that accompanies the Solar Prismatic colours.*

The same mirror was covered by a piece of pasteboard, which, through a proper opening, admitted all the visible colors to fall on its polished surfaces, but excluded every other ray of heat that might be either on the violet or on the red side, beyond the spectrum. The

299 thermometer in the focus rose 35 degrees above its stationary position in the direct red rays when the mirror was covered. "Thus the prismatic colours, if they are not themselves the heat-making rays, are at least accompanied by such as have a power of occasioning heat, and are liable to be regularly reflected."

4th Experiment. *Reflection of the Heat of a red-hot Poker.*

300 5th Experiment. *Reflection of the Heat of a Coal Fire by a plain Mirror.*

301 6th Experiment. *Reflection of Fire-heat by a Prism.*

302 7th Experiment. *Reflection of Invisible Solar Heat.*

On a board about 4 feet 6 inches long was placed at one end a small plain mirror, and at the other two sensitive thermometers. Upon this board was projected a prismatic spectrum, and just beyond the limit of the red rays the mirror was stationed so as to reflect invisible rays to the ball of one of the thermometers. In ten minutes

303 this thermometer stood four degrees above the other.

304 8th Experiment. *Reflection and Condensation of the Invisible Solar Rays.*

At the focus of a concave mirror was placed the ball of a thermometer. Upon the mirror was thrown a prismatic spectrum which covered half the mirror. This half was covered by a pasteboard screen so that only invisible rays were reflected to the ball of the thermometer. In one minute the thermometer rose 19 degrees.

305 9th Experiment. *Reflection of Invisible Culinary Heat.*

306–307 10th Experiment. *Reflection of the Invisible Rays of Heat of a Poker, cooled from being red-hot till it could no longer be seen in a dark Place.*

308 11th Experiment. *Refraction of Solar Heat.*

The rays from the sun, falling on the mirror of a Newtonian telescope 24 inches in diameter, were transmitted after reflection through the four lenses of an eye-piece and allowed to fall on the ball of a thermometer.

12th Experiment. *Refraction of the Heat of a Candle.*

309 The image of a candle flame was thrown upon the ball of a thermometer by a lens 1.1 in diameter.

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800 90 310 13th Experiment. *Refraction of the Heat that accompanies the Coloured part of the Prismatic Spectrum.*

A burning lens 9 inches in diameter was covered by a piece of pasteboard in which there was an opening of a sufficient size to admit all the coloured part of the prismatic spectrum. As the thermometer showed rise of temperature, the conclusions were, that if the coloured rays themselves are not of a heat-making nature, they are at least accompanied with rays that have the power of heating
311 bodies, and that these rays are subject to certain laws of refraction which cannot differ much from those affecting light.

311–312 14th Experiment. *Refraction of the heat of a Chimney Fire.* The same burning glass before the clear fire of a large grate.

313–314 15th Experiment. *Refraction of the Heat of a Red-hot Iron.* This was by a lens of 1.1 inches diameter.

315–316 16th Experiment. *Refraction of Fire-heat by an Instrument resembling a Telescope.*

317 17th Experiment. *Refraction of the Invisible rays of Solar Heat.* The burning lens of 9 inches diameter was half covered by a screen of pasteboard, upon which the prismatic spectrum was thrown, keeping the last visible red colour one-tenth of an inch from the edge of the pasteboard. The thermometer, which had its ball at the focus for red rays, showed great increase of temperature; but at the same time exhibited a slight red colouration. This occasioned a surmise that possibly the invisible rays of the sun might become visible, if they were properly condensed.

318 18th Experiment. *Trial to render the Invisible Rays of the Sun Visible by Condensation.*

The previous experiment was modified so that the last visible red colour was two tenths of an inch from the margin of the pasteboard. Here a marked increase of temperature was evinced without a vestige of light.

319 19th Experiment. *Refraction of Invisible Culinary Heat.*

A heated cylinder of iron was placed on one side of a lens of 1.1 inches diameter, and the ball of a thermometer in the secondary focus on the other side of the lens. A small pasteboard screen was alternately removed from before the thermometer and replaced, the thermometer exhibiting corresponding rise and fall of temperature, from a bright red heat of the cylinder down to its weakest state of black heat.

320–321 20th Experiment. *Confirmation of the 19th.*

322 "As we have now traced the rays which occasion heat, both solar and terrestrial, through all the varieties that were mentioned in the beginning of this paper, and have shown that in every state they are subject to the laws of reflection and refraction, it will be easy to perceive that I have made good a proof of the first three of my propositions. For the same experiments which have convinced us that, according to our second and third articles, heat is both reflexible and refrangible, establish also its radiant nature, and thus equally prove the first of them."

[Dated] Slough, near Windsor, April 26, 1800.

323–326 *Explanation of the Figures.* Plates XII, XII, XIV, XV, and XVI.

800 90 437 *Experiments on the Solar and on the Terrestrial Rays that occasion Heat; with a comparative View of the Laws to which Light and Heat, or rather the Rays which occasion them, are subject, in order to determine whether*

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they are the same or different. By WILLIAM HERSCHEL, LL. D., F. R. S. Part II. Read Nov. 6, 1800.

1800 90 438 "The next three articles of this paper will require, that while we shew the similarity between light and heat, we should at the same time point out some striking and substantial differences, which will occur in our experiments on the rays which occasion them, and on which hereafter we may proceed to argue, when the question reserved for the conclusion of this paper, whether light and heat be occasioned by the same or different rays, comes to be discussed."

ART. IV. *Different Refrangibility of the Rays of Heat.*

439 Construction of a curve, from experiments before described, the abscissas of which represent the arrangement of colours in the prismatic spectrum, and the ordinates the corresponding luminous intensity.

440 Construction of a curve which, in a similar manner, represents the distribution of heat in a prismatic spectrum.

441 "A mere inspection of the two figures, which have been drawn as lying on each other, will enable us now to see how very differently the prism disperses the heat-making rays, and those which occasion illumination. * * * These rays neither agree in their mean refrangibility nor in the situation of their maxima."

441–442 21st Experiment. *The sines of Refraction of the heat-making Rays are in a Constant Ratio to the sines of Incidence.* Ten different refracting angles of various media were used.

443 22nd Experiment. *Correction of the Different Refrangibility of Heat by contrary Refraction in Different Mediums.* An achromatic combination of two crown prisms and one flint deflected no heat outside the visible spectrum.

444 23rd Experiment. *In Burning-glasses the Focus of the Rays of Heat is Different from the Focus of the Rays of Light.*

445 ART. V. *Transmission of Heat-making Rays.*

446–448 Description of apparatus for this investigation.

447 [Foot-note.] Theory of the sensibility of thermometers.

449 *Transmission of Solar Heat through Colourless Substances.*

24th Experiment. The transmission of rays by a piece of bluish-white glass measured.

450 Reference to Table 7 at the end of the paper, which gives the proportion of light transmitted by various substances, solid and liquid, white and coloured.

451 25th Experiment. Transmission through a piece of flint glass ½ inch thick.

452–453 Experiments 26 to 30. Transmission through crown glass, coach glass, Iceland crystal, and two varieties of talc.

453 *Transmission of Solar Heat through Glasses of the prismatic colours.*

453–456 Experiments 31 to 43.

456 *Transmission of Solar Heat through Liquids.*

457–458 Experiments 44 to 49. Transmission through well-water, sea-water, spirits of wine, gin, and brandy.

458 *Transmission of Solar Heat through Scattering Substances.*

458–462 Experiments 50 to 62. Transmission through various pieces of ground glass, an olive-coloured glass, calcined talc, white paper, linen, white persian, and black muslin.

462 *Transmission of Terrestrial Flame-heat through various Substances.*

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1800	90	462–463	Description of apparatus used.
		464–470	Experiments 63 to 93. Transmission of heat from a candle flame through the various substances used before.
		470	*Transmission of the Solar Heat which is of an Equal Refrangibility with Red Prismatic Rays.*
		470–471	Description of apparatus used.
		471–476	Experiments 94 to 116. Transmission of red solar rays through the substances used before.
		476	*Transmission of Fire-Heat through various Substances.*
		476–477	Description of apparatus.
		477–485	Experiments 117 to 147. Transmission of heat from a grate fire through the same plates before used.
		485	*Transmission of the Invisible Rays of Solar Heat.*
		485–490	Experiments 148 to 169.
		490	*Transmission of Invisible Terrestrial Heat.*
		490–492	Method and apparatus employed.
		492–497	Experiments 170 to 194. Transmission of heat from a stove by the plates before used.
		497	ART. VI. *Scattering of Solar Heat.*
		497–498	Description of apparatus.
		499–506	Experiments 195 to 219. Determinations of the amount of heat scattered by various kinds of paper, textile fabrics, metals, &c.
		506	ART. VII. *Whether Light and Heat be occasioned by the same or by Different Rays.*
		506	"Before we enter into a discussion of this question it appears to me that we are authorized, by the experiments which have been delivered in this paper, to make certain conclusions that will entirely alter the form of our enquiry. Thus, from the 18th experiment it appears that 21 degrees of solar heat were given in one minute to a thermometer by rays which had no power of illuminating objects and which could not be rendered visible, notwithstanding they were brought together in the focus of a burning lens. The same has also been proved of terrestial heat in the 9th experiment, where in one minute 39° of it were given to a thermometer by rays totally invisible, even when condensed by a concave mirror. Hence it is established, by incontrovertible facts, that there are rays of heat, both solar and terrestrial, not endowed with a power of rendering objects visible. "It has also been proved, by the whole tenour of our prismatic experiments, that this invisible heat is continued, from the beginning of the least refrangible rays towards the most refrangible ones in a series of uninterrupted gradation, from a gentle beginning to a certain maximum, and that it afterwards declines as uniformly to a vanishing state. These phenomena have been ascertained by an instrument which, figuratively speaking, we may call blind, and which, therefore, could give us no information about light; yet, by its faithful report, the thermometer, which is the instrument alluded to, can leave no doubt about the existence of the different degrees of heat in the prismatic spectrum. "This consideration, as has been observed, must alter the form of our proposed inquiry, for the question being thus at least partly decided, since it is ascertained that we have rays of heat which give no light, it can only become a subject of inquiry whether

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some of these heat-making rays may not have a power of rendering objects visible, superadded to their now already established power of heating bodies."

1800 90 508 "It has been shown that the effect of heat and of illumination may be represented by the two united spectra which we have given." "Now when these are compared it appears that those who would have the rays of heat also to do the office of light must be obliged to maintain the following arbitrary and revolting positions, namely: that a set of rays conveying heat should all at once, in a certain part of the spectrum, begin to give a small degree of light; that this newly acquired power of illumination should increase while the power of heating is on the decline; that when the illuminating principle is come to a maximum it should in its turn also decline very rapidly and vanish at the same time with the power of heating. How can effects that are so opposite be ascribed to the same cause?"

509 Relation of the refrangibility of the maximum heat-making rays and that of the rays of maximum luminousity.

TABLE I.—Containing the results of experiments 24 to 30.

510 TABLE II.—Containing the results of experiments 31 to 43, followed by a discussion of the same.

511 TABLE III.—Results of experiments on liquids.

511 TABLE IV. Containing the stoppages occasioned by scattering substances.

512–519 Argument founded upon the data contained in these four tables. The general course of this argument is that, assuming the heat-making rays and rays of light to be of the same nature, a ratio of the efficacy of the invisible rays to that of the luminous rays derived from one set of experiments is incompatible with the ratio derived from any other set. Under the assumption that the heat-making rays are essentially different from light rays, this incompatibility does not appear.

520 TABLE V. *Stoppage of Prismatic Heat of the Refrangibility of the Red Rays, and of the Invisible Rays.*

[The measurements on dark-red glass here quoted is HERSCHEL'S decisive experiment, proving that heat-making rays are not the same by nature as the light rays. The experiment involves a photometric determination not described, the result of which is, however, quoted.]

521–523 Argument founded upon data in above table.

524 TABLE VI. Containing the results of the experiments on the transmission of terrestrial heat.

525–527 Showing the impossibility of explaining these results by any assumption as to the ratio of the efficacy of visible and invisible rays.

528 *Table of the Transmission of Terrestrial Scattered Light through various Substances; with a short Account of the Method by which the Results contained in this Table have been obtained.*

528–531 Description of the method and apparatus used, both being founded upon the principles of BOUGUER. The sources of scattered light were vanes of white paper illuminated by a lamp.

532–533 TABLE VII. This table contains the transmitting power for light of nearly all the substances used in the experiments of this paper.

533 *Table of the Proportional Terrestrial Light Scattered by various Substances.*

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1800 90 533–534 Method of determination.

534–535 TABLE VIII. Containing the relative scattering power of thirty-three bodies.

535–538 *Explanation of the Plates.*

1801 91 265 *Observations tending to investigate the Nature of the Sun in order to find the Causes or Symptoms of its variable Emission of Light and Heat; with Remarks on the Use that may possibly be drawn from Solar Observations.* By WILLIAM HERSCHEL, LL. D., F. R S. Read April 16, 1801.

265–266 Reference to HERSCHEL'S view, given on a former occasion, that the sun is a magnificent habitable globe; declaration that these more recent observations support that view; and a statement as to the importance of solar observations in their bearing upon the climate, together with an opinion that such observations will enable us to predict the character of a season.

267–268 Definitions of the terms, *openings, shallows, ridges, nodules, corrugations, indentations, and pores.*

269 Explanation of the form of the paper and the reasons for it.

270 OF OPENINGS. *Openings are Places where the luminous Clouds of the Sun are removed.*

[Foot-note.] For a geometrical proof of the depression of openings a reference to a paper by ALEXANDER WILSON, *Phil. Trans.*, vol. 64.

271 *Large Openings have generally Shallows about them. Many Openings are without Shallows. Small Openings are generally without Shallows. Openings have generally Ridges and Nodules about them.*

272 *Openings have a Tendency to run into each other. New Openings break out near other Openings. Probable Cause of Openings.*

273 *Direction and Operation of the disturbing Cause.*

274 *Maxima of Openings.*

275 *There is some Difference in the colour of Openings. Openings divide when they are decaying.*

276 *Decaying Openings sometimes increase again. When Openings are divided they grow less and vanish. Decayed Openings sometimes become large Indentations.*

277 *Decaying Openings turn sometimes into Pores. When Openings are vanished, they leave Disturbance behind.*

278 *Apparent View into the Openings, under luminous Ridges and Shallows. Depth of the Openings indicated by their Darkness.*

279 *Distance between the Shallows and solar Surface, indicated by the free Motion of low Clouds.*

280 OF SHALLOWS. *Shallows are depressed below the general Surface of the Sun; and are Places where the luminous solar Clouds of the upper Regions are removed. The Thickness of the Shallows is visible.*

281 *Sometimes there are Shallows without Openings in them. Incipient Shallows come from the Openings, or branch out from Shallows already formed, and go forwards. Probable Cause of Shallows.*

283 *Shallows have no Corrugations, but are tufted. Decay of Shallows.*

283 OF RIDGES. *Ridges are Elevations above the general Surface of the luminous Clouds of the Sun.*

284 *Length of a Ridge. Ridges generally accompany Openings. Ridges are also often in Places where there are no Openings.*

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1801 91 285 *Ridges disperse very soon. Different Causes of Ridges hinted at.*

286 OF NODULES. *Nodules are small, but highly elevated, luminous Places. Nodules may be Ridges fore-shortened.*

287 OF CORRUGATIONS. *Corrugations consist of Elevations and Depressions. Corrugations extend all over the Surface of the Sun.*

288 *Dispersed Ridges or Nodules make Corrugations. Corrugations change their Shape and Situation; they increase, diminish, divide, and vanish quickly.*

289 OF INDENTATIONS. *The dark places of Corrugations are Indentations.*

290 *Indentations are without Openings. In some places the Indentations contain small Openings. The Elevations and Indentations of Corrugations are of different Figures. Indentations change to Openings.*

291 *Indentations are of the same Nature as Shallows. Indentations are low Places, which often contain very small Openings. Indentations are of different Sizes. Indentations are extended all over the Sun.*

292 *With low magnifying Powers, Indentations will appear like Points.*

292 OF PORES. *The low places of Indentations are Pores. Pores increase sometimes, and become Openings. Pores vanish quickly.*

293 OF THE REGIONS OF SOLAR CLOUDS.
Changes in the Solar Clouds happen continually.

294 *There are two different Regions of Solar Clouds.*
The inferior clouds are opaque, and probably not unlike those of our Planet.

295 *Quantity of light reflected from the inferior Planetary Clouds.*

297 *Indentations are planetary Clouds, reflecting light through the open Parts of the Corrugations. The opaque inferior Clouds probably suffer but little of the light of the self-luminous superior Clouds to come to the Body of the Sun. Motion of the inferior Clouds.*

298 *Motion of the superior Clouds.*

299 *Eminent Use of the planetary Clouds.*

300 OF THE SOLAR ATMOSPHERE. *The Sun has a planetary Atmosphere. The Sun's planetary Atmosphere extends to a great Height. The planetary Atmosphere of the Sun is of great Density.*

301 *The Solar Atmosphere, like ours, is subject to Agitations, such as with us are occasioned by Winds. There is some clear Atmospheric Space, between the solid Body of the Sun and the lowest Region of the Clouds.*

302 *The Sun's planetary Atmosphere is transparent.*

303 THEORETICAL EXPLANATION OF THE SOLAR PHENOMENA.
GENERATION OF PORES.

304 *Formation of Corrugations. Cause of Indentations.*

305 *Cause of the mottled Appearance of the Sun. Formation of small Openings, Ridges, and Nodules. Production of large Openings and Shallows.*

306 SIGNS OF SCARCITY OF LUMINOUS MATTER IN THE SUN.
Visible Deficiency of empyreal Clouds. A perfect Calm in the upper Regions of solar Clouds. Want of Openings, Ridges, and Nodules.

307 *Many Indentations without, and others with, changeable Pores.*

308 SIGNS OF ABUNDANCE OF LUMINOUS MATTER IN THE SUN.
Visible Increase of empyreal Clouds. Many Openings, Ridges, and Nodules.

310 *Coarse and luminous Corrugations.*
[Each of the above headings is followed by quotations from HERSCHEL'S Journals in confirmation].

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1801 91 310–318 A general discussion of the conclusions to be deduced from the observations quoted in this paper. [To HERSCHEL it seemed that the absence of Openings, Ridges, and Nodules, indicated a scarcity of luminous matter in the sun, and, therefore, that the seasons during which such conditions of the sun were recorded ought to be of a lower temperature. He finds support for this view in the higher price of wheat during the five recorded periods of scarcity of sun spots.]

318 Explanation of the 1st, 2d, 11th, and 12th figures of Plates XVIII and XIX.

1801 91 354 *Additional Observations tending to investigate the Symptoms of the variable Emission of the Light and Heat of the Sun; with Trials to set aside darkening Glasses, by transmitting the Solar Rays through Liquids; and a few Remarks to remove Objections that might be made against some of the Arguments contained in the former Paper.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read May 14, 1801.

354–355 Considerations as to the relations of the condition of the solar surface and the weather.

355 "Before I proceed, I must hint to those who may be willing to attend to this subject, that I have a strong suspicion that one half of our sun is less favorable to a copious emission of rays than the other; and that its variable lustre may possibly appear to other solar systems, as irregular periodical stars are seen by us; but, whether this arises from some permanent construction of the solar surface, or is
356 merely an accidental circumstance, must be left to future investigation: it should, however, be carefully attended to."

356–361 *Observations of the sun.*

361 Description of a skeleton eye-piece, into the vacancy of which may be placed a moveable trough, shut at the ends with plain glasses, so that the sun's rays may be made to pass through any liquid, such as spirits of wine, Port wine, mixture of ink and water, etc., placed in the trough.

362 EXPLANATION OF THE FIGURES. Plate XXVIII.

1802 92 213 *Observations on the two lately discovered bodies.* [Ceres and Pallas.] By WILLIAM HERSCHEL, LL. D., F. R. S. Read May 6, 1802.

213 [*Ceres*] is of very small size. [Foot-note.] Its real diameter is not as great as three-eighths of our moon.

214 *Magnitude of the new Stars.* [*Ceres* and *Pallas.*]

April 1, 1802. I placed a lucid disc at a considerable distance from the eye and viewed with one eye the magnified star (seen with a 7-foot reflector) and the lucid disc with the other.

215 By this means it appears that the real diameter of *Ceres* is not above 0''.40.

215 April 21. With a ten-foot reflector the same experiment gave 0''.38.

217 April 22. For *Ceres* the diameter was 0''.22. For *Pallas* 0''.17 and 0''.13.

218 The real diameters are, then, *Ceres* 161.6 miles, *Pallas* 147 miles.

219 *Of Satellites.* [Observations on this subject.]

220 There is certainly no satellite to *Ceres* that can be seen with the 20-foot reflector.

220 *Of the Color of the new Stars.* The color of *Ceres* is ruddy but not very deep. *Ceres* is more ruddy than *Pallas*. *Pallas* is of a dusky whitish color.

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1802	92	221	*Of the Appearances of the new stars with regard to a Disk.*
			Ceres has a visible disk. *Pallas'* disk I would rather call a nucleus.
		221	*Of the appearances of the new stars, with regard to an atmosphere or coma.*
			[Observations] probably no coma.
		223	*On the nature of the new Stars.*
		223	What are these new stars; are they planets or are they comets?
		224	Planets defined (by 7 particular properties).
		225	Our new stars cannot be called planets.
		226	Comets defined (by 5 particular properties).
		228	The new stars are not comets. They should be called *Asteroids* from their resemblance to small stars.
		229	Asteroids defined.
		229	Statement of the reasons we have for expecting that additional asteroids may probably be soon found out.
		229	I have already made five reviews of the zodiac without detecting any of these asteroids; their motion and not their appearance will be the future means of detecting them.
		230	We have reason to believe that a number of asteroids may remain concealed.
		230	Comets may become asteroids.
		231	*Additional observations relating to the appearances of the asteroids Ceres and Pallas.*
			The coma of *Ceres* not much greater than that of stars of the same magnitude.
		232	The fixed stars differ considerably in this respect among themselves.
		232	The coma of *Pallas* not much more than for equal fixed stars.
1802	92	477	*Catalogue of* 500 *new Nebulæ, nebulous Stars, planetary nebulæ and Clusters of Stars; with Remarks on the construction of the Heavens.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read July 1, 1802.
			After a sufficient number of celestial objects is found, there is a necessity for a scientific classification. The former classification was only for the convenience of the observer.
		478	ENUMERATION OF THE PARTS THAT ENTER INTO THE CONSTRUCTION OF THE HEAVENS.
			I. *Of Insulated Stars.*
		479	Notion of an insulated star—our sun is one.
		480	The milky way consists of stars very differently scattered from those which are immediately about us.
		480	By analogy we may admit that every insulated star may be attended with planets, etc. I should hesitate to extend this analogy to every star in the heavens, and even think that probably we can only look for solar systems among insulated stars.
		480	II. *Of Binary Sidereal Systems or Double Stars.*
		481	Difference between a double and a binary star.
		482	Difference between solar and sidereal systems.
		482	No insulated stars of nearly an equal size and distance can appear double to us.
		483	Proof of this.
		485	Casual situations will not account for the multiplied phenomena of double stars, and their existence is owing to a general law of nature—gravitation is that law.
		486	I shall soon communicate a series of observations on double stars, *proving that many of them have already changed their situation with*

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regard to each other in a progressive course, denoting a periodical revolution round each other.

Our sun does not belong to such a system.

III. *Of more complicated Sidereal Systems, or treble, quadruple, quintuple, and multiple stars.*

1802 92 487 Theorem as to the permanent connection of revolving stars, when the forces acting on any one of them reduced to a direction as coming from the empty centre are in the direct ratio of the distances from that centre.

488–494 Hypothetical examples of such multiple stars.

494 Such combinations as I have mentioned are not the inventions of fancy; they have an actual existence; and, were it necessary, I could point them out by thousands.

495 I do not imagine that I have pointed out the actual manner in which they are held together, but only the possibilities of such unions.

495 IV. *Of Clustering Stars and the Milky Way.*

Marks of clustering in the milky way. Example of the stars between β and ζ Cygni.

496 "We may indeed partly ascribe the increase, both of brightness and of apparent compression, to a greater depth of the space which contains these stars; but this will equally tend to show their clustering condition, for since the increase of brightness is gradual, the space containing the clustering stars must tend to a spherical form if the gradual increase of brightness is to be explained by the situation of the stars."

V. *Of groups of Stars.* Definition.

497 VI. *Of clusters of Stars.* Definition.

VII. *Of Nebulæ.* Perhaps they are all to be resolved into the three last-mentioned species.

498 Power of a telescope to penetrate not only space but time past.

499 VIII. *Of Stars with Burs or Stellar Nebulæ.*

IX. *Of Milky Nebulosity.*

Probably of two kinds. 1st, apparent, which is formed by distant ["widely-extended"] clustering stars; and, 2d, real, and possibly at no very great distance from us. The nebula of *Orion* of this latter kind.

500 X. *Of Nebulous Stars.*

501 XI. *Of Planetary Nebulæ.*

Perhaps they are allied to nebulous stars.

XII. *Of Planetary Nebulæ with Centres.*

503 Catalogue.

Class I	No. 216	to	No. 228
II	No. 769	to	No. 907
III	No. 748	to	No. 978
IV	No. 59	to	No. 78
V	No. 45	to	No. 52
VI	No. 36	to	No. 42
VII	No. 56	to	No. 67
VIII	No. 79	to	No. 88

528 Plates XVI and XVII, 16 figures of hypothetical orbits of multiple stars.

1803 93 214 *Observations of the Transit of Mercury over the disk of the Sun; to which is added an investigation of the causes which often prevent the proper*

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			action of Mirrors. By WILLIAM HERSCHEL, LL. D., F. R. S. Read February 10, 1803.
1803	93	214	The observations were made (1802, Nov. 9) with a *glass* mirror of 7 feet focus and 6.3 inches aperture under favorable conditions, and
		215	also with a 10-feet reflector. Eye-pieces made of dark-green glass and others smoked on the side next the eye were used.
		216	No ring about the planet; no distortion of the limbs of the sun or *Mercury* at egress.
		217	*Mercury* was perfectly spherical in figure.
		217	*Observations and experiments relating to the causes which often affect mir rors, so as to prevent their showing objects distinctly.*
		217	The experience of many years will enable me to assign the principa causes of disappointments in the use of mirrors.
		218	The following observations have all been made with specula of undoubted goodness, so that every cause which impeded their proper action was extrinsic.
		218	*Moisture in the air.* Damp air is no enemy to vision.
		219	*Fogs.*
		220	*Frost.*
		221	*Hoar-Frost; Dry-Air.*
		222	*Northern-Lights; Windy-Weather; Fine in Appearance.*
		223	*Over a Building; The Telescope lately brought out.*
		224	*Confined Place; Haziness and Clouds.*
		225	*Focal-length.*
		226	In order to see well with telescopes it is required that the temperature of the atmosphere and mirror should be uniform and the air fraught with moisture.
			All the preceding observations are accounted for by this principle.
		228	Experiments [on the effects of change of focal length of a speculum.] Heat applied back and front of a glass speculum lengthened the focus.
		230	With a metal mirror the focus became first shorter and then lengthened.
		231	In observing the sun similar effects may arise.
		232	Perhaps these might be counteracted by an application of heat to the back of the mirror or by an interception of it in front.
1803	93	339	*Account of the changes that have happened during the last Twenty-Five Years in the Relative Situation of Double-Stars; with an investigation of the Cause to which they are owing.* By WILLIAM HERSCHEL, LL.D., F. R. S. Read June 9, 1803.
		339	In *Phil. Trans.*, 1802, p. 477, I have defined insulated stars. The discovery of [*Ceres* and *Pallas*] has enlarged our knowledge of the system of insulated stars.
		340	I have already shown that two stars may revolve about their common centre of gravity; and that it is probable there would be many such binary systems among all the stars of the heavens. But neither of these reasons is a proof of the actual existence of such systems. I will here give an account of observations which will go to prove that many of them are not merely double in appearance, but are real binary combinations, intimately held together by the bond of mutual attraction.
		341	In Plate VII, Fig. 1, call the place of the sun, O, of the larger star of a double star, α, of the smaller, χ.

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03 93 341 There are three motions to be considered of the bodies O, α, χ; a motion of one, of two, or of all three.

341 *Single Motions.* If α and O are at rest, a motion of χ may be assumed so as perfectly to explain any change of distance or of angle of position of the two stars.

342 The effect of a motion of α or of O explained.

343 *Double motions.*

344 *Motions of the three bodies.*

345 [Observations] case of α *Geminorum.*
The distance has remained about constant for 23½ years.

345 In a reflector the apparent diameter of a star depends upon: the aperture with respect to the focal length; the distinctness of the mirror; the magnifying power; the state of the atmosphere. By contracting the aperture we can increase the apparent diameter; want of distinctness does the same thing; an increase of magnifying power increases the distance apart of two stars, but this increase is not proportional to the increase of the power, and sooner or later comes to a maximum; the state of the atmosphere is the most material condition, as we cannot alter it.

346 The other three causes are at our disposal. I took ten different mirrors of 7 feet focus, 6.3 inches aperture, magnifying power 460. With these, one after another, I viewed α *Geminorum.* With each one the distance of the components was the same.

346 When double stars are first seen they appear nearer together than later.

347 I have known it to take up two or three months before the eye was sufficiently acquainted with the object to judge with the requisite precision.

347 The error of this method of estimating the distance of these two stars is not above 0″.34.

348 The angle of position of these stars was in 1779, 32° 47′ north-preceding; it is now only 10° 53′. In 23½ years it has diminished 21° 54′; this change has been regular and gradual.

348 Accuracy of the angles of position investigated by the deviation of separate measures from the mean.

349 This micrometer, then, will give the position of a double star true to about 1° from 2 measures; in the worst circumstances the error will not be 3°.

350 The cause of this change must be examined. A revolving star would explain the alteration of the angle of position with no alteration of the distance. As we have no precedent for, this it will be right to examine whether the change cannot be accounted for by the proper motions of the stars, or of the sun.

350 *Single motions* [examined].

355 All are inconsistent with my observations.

356 The proper motion of the sun must be admitted in such a direction and of such a velocity as will satisfy the mean direction and velocity of the general proper motions of the stars.

356 *Double Motion.* This hypothesis is not maintainable.

359 *Motion of the three Bodies.* This hypothesis will explain the observations, but in so complex a way as to leave no doubt that we should give the preference [to the hypothesis of a revolution of the stars themselves].

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1803 93 362 Table of measures of *Castor* and comparison of calculated and observed angles.

363 An observation of BRADLEY'S on *Castor* (1759) quoted.

365 New table of calculated and observed angles, including BRADLEY'S observations. The arc 45° 39′ has been described in 43 years 142 days.

365 The regularity of the motions gives us reason to conclude that the orbits of these stars are circular and at right angles to the line of sight; if this be nearly true the time of a revolution will be about 342 years and 2 months.

366–372 *γ Leonis.* [This case considered as before.]

372 Table of observations: the period is about 1,200 years.

372 *ε Boötis.*

378 *ζ Herculis.*

380 *δ Serpentis.*

381 *γ Virginis.*

382–3 Plates VII and VIII—figures of orbits.

1804 94 353 *Continuation of an Account of the Changes that have happened in the relative situation of double Stars.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 7, 1804.

353 In my former paper (*Phil. Trans.*, 1803, p. 339) I gave the changes in the situation of six double stars.

353 I used the best observations I had of the position of *Castor*, but as the proper motions of 36 principal stars published in the Greenwich observations give the motion of this star different from what I used, it will be necessary to review the arguments in the same order as in the preceding paper.

358 [The former conclusions in regard to *Castor* are confirmed.]

359 In the further list of 50 double stars here given, 28 have undergone only moderate changes, less than 10°.

Thirteen have altered their situation above 10° but less than 20°; 3 stars have changed more than 20°; the six remaining have changed between 30° and 130°.

359–384 [The various pairs considered and observations given.]

360 I have no longer supposed the solar motion to be directed to *λ Herculis*, but to a point at no very great distance from this star.

1805 95 31 *Experiments for ascertaining how far Telescopes will enable us to determine very small Angles, and to distinguish the real from the spurious Diameters of celestial and terrestial Objects; with an Application of the Result of these Experiments to a Series of Observations on the Nature and Magnitude of* Mr. HARDING'S *lately discovered Star.* [*Juno.*] By WILLIAM HERSCHEL, LL. D., F. R. S. Read December 6, 1804.

31 "We know that a very thin line may be perceived and that objects may be seen when they subtend a very small angle; but the case I wanted to determine relates to a visible disk, a round, well-defined appearance, which we may without hesitation affirm to be circular, if not spherical."

[In 1774 HERSCHEL found that a square area could not be distinguished from an equal circular one till the diameter of the latter came to subtend an angle of 2′ 17″.]

32 1st Experiment, *with the Heads of Pins.*

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95 33 These objects were observed at a distance of 2407.85 inches from the mirror of a ten-feet reflecting telescope. It was found that in the telescope a body subtending the magnified angle of 2′ 19″ could easily be recognized as round.

2d Experiment, *with small Globules of Sealing-wax.*

34 It appeared that with a substance not reflecting much light the magnified angle must be between 4 and 5 minutes before we can see it round.

35 3d Experiment, *with Globules of Silver.*

36–57 4th Experiment, *with Globules of Pitch, Bees-wax, and Brimstone.*

38–39 5th Experiment, *with Objects at a greater Distance.*

40 6th Experiment, *with illuminated Globules.*

40 SPURIOUS DIAMETERS OF CELESTIAL OBJECTS.

Observations and Experiments, with Remarks.

41 With stars, the spurious diameters are larger than the real ones, which are too small to be seen.

The spurious diameters of stars are of different sizes, and under the same circumstances their dimensions are of a permanent nature.

The spurious diameters of the stars are differently coloured.

42 Their spurious diameters are lessened by increasing the magnifying power, but in a much less ratio.

Magnifying power acts less on the large diameters and more on the small ones. When the aperture of the telescope is lessened, it will occasion an increase of the spurious diameters; but this increase is not proportional to the diameters of the stars, acting more upon the
43 small spurious diameters and less upon the large ones. Very small stars, however, lose their spurious diameters, and become nebulous.

The spurious diameter of a star is reduced by haziness of the atmosphere. At a low altitude a star makes a spectrum, being coloured by the prismatic power of the atmosphere.

44 SPURIOUS DIAMETERS OF TERRESTRIAL OBJECTS, WITH SIMILAR REMARKS.

7th Experiment *with Silver Globules.*

45 8th Experiment.

The luminous spots or spurious disks of the globules were of unequal diameters.

9th Experiment. 10th Experiment.

46 11th Experiment. 12th Experiment.

47 13th Experiment. 14th Experiment.

48–49 15th Experiment, *with Drops of Quicksilver.*

50 [These experiments, from the 7th to the 15th, inclusive, prove that all the remarks made concerning the spurious disks of stars are also applicable to sufficiently small and bright terrestrial objects.]

16th Experiment, *with black and white Circles.*

51 17th Experiment, *with different Illumination.*

18th Experiment. *Measures of spurious Disks.*

With drops of quicksilver, the spurious disks were measured by means of distant disks of known diameters upon which they were projected. By covering the mirror with screens of different apertures, and also
52 by stopping out its center by circular screens of different size, it was found that the sizes of the spurious disks were not determined by the quantity of light reflected from the mirror, but rather by the

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1805 95 53 part of the mirror used. Thus the inside rays of a mirror increase the diameter of these disks, whereas the outside rays alone have a greater effect in reducing it than they do when the inside rays are left to join with them. This affords a criterion as to whether a disk is real or spurious.

19th Experiment. *Trial of Estimations.*

20th Experiment. *Use of the Criterion.*

54 21st Experiment. *Measures of the comparative Amount of the spurious Diameters produced by the Inside and Outside Rays.*

22d Experiment. *Trial of the Criterion on celestial Objects.*

55 22d Experiment. [Another trial.]

55–61 OBSERVATIONS ON THE NATURE AND MAGNITUDE OF MR. HARDING'S LATELY-DISCOVERED STAR.

61 RESULTS AND APPLICATION OF THE EXPERIMENTS AND OBSERVATIONS.

62 There is a limit to the size of objects [½ second in HERSCHEL'S 10-foot telescope] above which a mere increase in magnifying power will betray the real disk. By the criterion of the outside and inside rays, an object of half this angular diameter may be shown to have real dimensions, but below this value the telescope cannot distinguish between a real and spurious diameter.

63–64 Remarks on the class of celestial bodies to which the new star belongs, and a justification of the term ASTEROID as applied to them.

[Dated] Slough, near Windsor, December 1, 1804.

1805 95 233 *On the direction and velocity of the Motion of the Sun, and Solar System.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read May 16, 1805.

233 Dr. MASKELYNE'S Table of the proper motions of 36 stars proves the motions of the stars of the first brightness, such as are probably in our immediate neighborhood. The changes in position of minute stars that I have ascertained prove that motions are equally carried on in the remotest parts of space.

233 In 1783 I deduced from the proper motions of stars, with a high degree of probability, a motion of the sun and solar system towards λ *Herculis.*

234 The present paper will treat [only] of the *direction* of the solar motion.

234 *Reasons for admitting a solar motion.*

It may appear singular that I should again think it necessary to give reasons for this. The cause is that [in 1783 I proposed to] take away the various proper motions of stars by investing the sun with a contrary one. Now, however, [I find that] the solar motion will reveal so many concealed real motions that we shall have more of them than would be necessary were the sun at rest. Hence the necessity for admitting the solar motion ought to be well established.

235 *Theoretical considerations.*

235 A view of the motions of moons around planets, and these again round the sun, may suggest the motion of the latter round some unknown centre. The solar motion was suggested by LAMBERT; Dr. WILSON has shown its possibility from theoretical principles, and DE LA LANDE its probability. The rotation of the sun indicates a motion of translation; the cause of both is unknown.

236 The periodical stars should be examined with this idea. Conversely stars that have a motion in space may be surmised to have also a rotation on their axes.

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1805 95 236 *Symptoms of parallactic Motions.*
Three sorts of motions explained by Fig. 1, Plate VII.
237 The parallactic, the real, and the apparent motions.
238 Since a motion of the sun will occasion parallactic motions of the stars, these again must indicate a solar motion. To ascertain whether parallactic motions exist we must choose the brightest stars which are most affected by solar motion, they being probably the nearest to the sun.
238 We distinguish parallactic from real motions by the direction of the motion. If a solar motion exists all parallactic motions will be opposite to it; real motions will be dispersed indiscriminately to all parts of space.
239 The point towards which the sun moves is the apex of solar motion; the opposite point is the parallactic centre.
240 Table I. Ten positions of the solar apex from first magnitude stars.
241 Fifteen positions from fainter stars stated.
242 *Changes in the position of double Stars.* Among the 56 stars which I have given, the changes of more than half appear to be [due to a solar motion].
242 *Incongruity of proper Motions.*
242 *Sidereal occultation of a small Star.*
As far as we can judge at present the vanishing of the small star near δ *Cygni* is only a parallactic disappearance. A real motion would also explain it.
244 *Direction of the Solar Motion.*
248 When we are in search of an apex for the solar motion, it ought to be so fixed as to be equally favorable to every star. * * * Our aim should be to reduce the proper motions of the stars to their lowest quantities.
249 Table II of the direction and quantity of the apparent motion of six stars, supposing the sun to move towards λ *Herculis.*
251 Table III of the angles of the parallactic motion with the parallel; and Table IV, angles of the apparent with the parallactic motion.
252 Table V. Quantities and sum of the least real Motions.
253 Assuming the apex of solar motion to be in R. A. 270° 15′, N. P. D. 54° 45′, Table VI is computed: it is similar to Tables III, IV, V.
254 Assuming the apex R. A. 245° 52′ 30″, N. P. D. 40° 22′, Table VII [like Table VI] is calculated.
255 Although the great proper motions of *Arcturus, Procyon,* and *Sirius* are strong indications of their being affected by parallax, it is not probable that their apparent changes are entirely due to solar motion.
256 Observation shows that proper motions do exist: we should choose that apex which will take away more real motion than any other, or we should put the apex in R. A. 245° 52′ 30″, N. P. D. 40° 22′.

1805 95 272 *Observations on the singular Figure of the planet Saturn.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 20, 1805.
272 [Brief account of the particularities of the system of *Saturn.*]
272 There is a singularity left which distinguishes the figure of *Saturn* from that of all the other planets. In 1776 I perceived that the
273 body of *Saturn* was not round. In 1781 I found it was flattened at the poles more than *Jupiter.* In 1789 I measured the polar and equatorial diameters, and prepossessed with the idea of its being spheroidical I [paid no attention to other diameters].

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1805	95	273	Observations on *Saturn:* [from 1805, April 12, to June 2] 1805, April 12. The ring is brighter than the body, and whiter.
		274	April 18. The figure of *Saturn* is different from the spheroidical figure of *Jupiter*. The 4 points of greatest curvature are in latitude 46° 38′.
		275	The shadow of the ring on the body is broader at the ends than in the middle.
		275	April 19. The figure of *Saturn* is like a parallelogram with the four corners rounded off deeply. The latitude of the four points of greatest curvature is 45° 44′.5.
		276–277	May 5–13. *Saturn* and *Jupiter* were viewed alternately [and the preceding remarks confirmed].
		279	The real *Saturn* compared with the figure in *Phil. Trans.*, 1790, p. 17. The two did not agree. I then modified the latter and made them agree. An exact copy is given in Plate IX.
		280	Dimensions of the parts given.
1806	96	205	*On the Quantity and Velocity of the Solar Motion.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read February 27, 1806.
		205	The direction of the solar motion was ascertained in a former paper: the velocity is now in question.
		205	The proper motions, reduced to one direction, have been called quantities, to distinguish them from the velocities of the moving stars, required to produce those motions. The same distinction must be kept with respect to the velocity of the solar motion.
		205	At a given distance, when the quantity of the solar motion is known, its velocity is known, and every approximation towards a knowledge of the distance of a star of the first magnitude will be one toward a knowledge of the real solar velocity. It is otherwise with a star, for the angle of the direction of its motion with the visual ray is unknown.
		205	I shall use the former six stars in the present paper.
		206	*Proportional distance of the Stars.*
		207	I propose the following arrangement: Table VIII, *proportional Distances of Stars; Sirius,* 1.00; *Arcturus,* 1.20; *Capella,* 1.25; *Lyra,* 1.30; *Aldebaran* and *Procyon,* 1.40.
		208	I have tried all the known and many new ways of measuring the comparative light of the stars, and no one gives a satisfactory result. When we have more authentic data, the calculation may be repeated.
		208	*Effect of the increase and decrease of the Solar Motion and Conditions to be observed in the Investigation of its Quantity.*
		209	Table IX. In 6 columns: Stars; Apparent motion; Solar motion; Parallactic motion; Real motion; Velocities.
		210	It is not the motions but the velocities which must be equalized.
		211	It is assumed that their real motions are at right angles to the visual ray. [The objection to this considered.]
		213	*Calculations for drawing Figures that will represent the observed motions of the Stars.*
			These are of two classes; the first will remain unaltered whatsoever the solar motion; the second must be adjusted to every change [of solar motion].
		214	We must assume relative distances for the rest of our stars.

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6 96 215 Table X contains the result of calculation of the permanent quantities. It has six columns: (1) gives the star's name; (2) its proportional distance; (3) apparent motion; (4) Direction with the parallel; (5) Direction with the parallactic motion; (6) Velocity. [There are 36 stars.]

216 Plate IV, Fig. 1 and Fig. 3, exhibits columns 3, 4, and 5 graphically. Fig. 2 and Fig. 4 give the velocities.

217 *Remarks on the sidereal Motions as they are represented from Observation.*
Fig. 1 (from observation) shows that there must be some physical cause which gives a bias to the directions in which the stars are moving. Discussion of Figs. 2, 3, 4.

219 *The Solar Motion and its direction assigned in the first part of this paper are confirmed by the Phenomena attending the observed motions of 36 stars.*

221 *Trial of the method to obtain the Quantity of the Solar Motion by its Rank among the sidereal Velocities.*

222 *Calculations for investigating the Consequences arising from any proposed Quantity of Solar Motion and for delineating them by proper Figures.*

223 Table XI contains 5 columns: (1) name of star, including the sun; (2) Parallactic Motion; (3) Real Motion; (4) Parallactic Angle; (5) Velocity.

224 Figs. 5 and 6 illustrate Table XI.

224 *Remarks that lead to a necessary examination of the Cause of the sidereal Motions.*

225 A motion of the stars may arise from mutual gravitation or from an original projectile force. Both these causes act in the solar system.

225 The similar direction of the motion of a group of stars may be ascribed to their similar projectile motions.

227 *Considerations of the attractive Power required for a sufficient Velocity of the sidereal Motions.*
The mere attraction of neighboring stars acting upon each other cannot be the cause of proper motions. *Sirius* and the Sun from that cause would approach yearly by less than 0″.000000005 to an eye at the distance of *Sirius* and supposing its parallax 1″.

228 A centre of attraction must then be assumed, and original projectile
229 motions must be supposed.

229 The centre of attraction may be one mass or a group.

230 Or it may be a union of groups; like two clusters 12° apart which are near the line of the solar motion.

231 The Milky Way will furnish centres of attraction.

231 Independent of the solar motion, the action of distant centres of attraction will be required to explain the proper motions of stars. If the Sun be at rest *Arcturus* moves 2″ a year; and this must be due to a projectile motion and the attraction of far distant centers.

232 *Determination of the Quantity of the Solar Motion.* The rank assigned to the solar motion is a perfect medium among the [36] sidereal velocities [which have been considered.]

233 The quantity of the solar motion is such that to an eye placed at right angles to its direction, and at the distance from *Sirius*, it would be annually 1″.116992.

234 *Concluding Remarks and Inferences.* [Objections considered.]

234 When a general knowledge of the proper motions of all the stars of the 1st, 2d, and 3d magnitudes has been obtained, the present calculation can be repeated by the same methods.

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1806 96 235 The result of calculations founded on facts, such as we must admit the proper motions of the stars to be, should give us useful information, to satisfy the inquisitive mind or to lead us on to new discoveries. The establishment of the solar motion answers both these ends. Our inquiries should not terminate here. A paper on general Gravitation [by Dr. WILSON] with what is said here, puts us within reach of a link of the chain which connects the principles of the solar and sidereal motions with those which are the cause of so many orbitual ones.

236 What has been said before of the Sun as an insulated star does not contradict the present idea of its making one of a very extensive system.

237 The insulation refers merely to a supposed binary combination with some neighboring star.

1806 96 455 *Observations and Remarks on the Figure, the Climate, and the Atmosphere of Saturn and its Ring.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 26, 1806.

455–457 [Account of HERSCHEL's observations on the figure of the ball.] Plate XXI, Fig. 1, represents *Saturn* in 1789, and Fig. 2, in 1805, May 5.

458 To discover the flattening of the figure of the ball a high magnifying power (500) was necessary. A lower power will afterwards show it. No error could arise from the defalcation of light May 5, 1805.

459–464 *Observations of the figure of Saturn.*

462 The flattening at the poles of *Saturn* is more extensive than on *Jupiter*. The curvature in high latitudes is also greater. At the equator it is rather less. Upon the whole the shape of the globe of *Saturn* is not such as a rotatory motion alone could have given it.

462 1806, June 3. The shadow of the ring on the ball is broader at the ends than in the middle.

463 The breadth of the ring is to the space between the ring and the ball as about 5 to 4. The ring appears to be sloping towards the ball.

463 The shadow of the ball on the ring is not parallel with the outline of *Saturn*.

464 *Observations on the periodical changes of color of the polar regions of Saturn.* In the observations of *Mars* (*Phil. Trans.*, 1784, p. 260) it has been shown that a periodical change takes place in the extent and brightness of the polar spots. I have suggested that this may be due [to frozen regions at the poles, varying in size as they are more or less exposed to the Sun.]

The following observations may lead to similar conclusions with respect to *Saturn*.

466 The gradual change of color of the polar region during a Saturnian year seems to be in a great measure ascertained. This can only be confirmed by a long series of observations.

466 *On the atmosphere of Saturn.*

From observations we may infer the existence of a Saturnian atmosphere.

467 A probability that the ring of Saturn has an atmosphere has been pointed out in a former paper.

[Dated] Slough near Windsor, June 12, 1806.

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1807 97 180 *Experiments for investigating the Cause of the coloured concentric Rings, discovered by* Sir ISAAC NEWTON, *between two Object-glasses laid upon one another.* By WILLIAM HERSCHEL, LL D., F. R. S. Read February 5, 1807.

180–181 Introduction.

182–185 I. *Of different methods to make one set of concentric rings visible.*

185–186 II. *Of seeing Rings by Transmission.*

187–188 III. *Of Shadows.* When two or more sets of rings are to be examined they may be distinguished by casting the shadow of a pointed penknife upon one set or another.

188–193 IV. *Of two sets of Rings.*

193–194 V. *Of three sets of Rings.*

195 VI. *Of four sets of Rings.*

195–196 VII. *Of the Size of the Rings.*

196 VIII. *Of Contact.*

197 IX. *Of Measuring Rings.*

197–198 X. *Of the Number of Rings.*

198–199 XI. *Of the Effect of Pressure on the Colour of the Rings.*

199–200 XII. *Of diluting and concentrating the Colours.* When the rings grow wider by using a lens of larger radius, they are said to be diluted.

201 XIII. *Of the order of the Colours.*

201–202 XIV. *Of the alternate Colour and Size of the Rings belonging to the primary and dependent Sets.* Certain of the dependent sets are rings by transmission as seen reflected at the back surface of the lower plate.

202–203 XV. *Of the sudden Change of the Size and Colour of the Rings in different Sets.* This is brought about by letting the shadow of the knife-blade fall on one or the other set.

204–206 XVI. *Of the course of the Rays by which different Sets of Rings are seen.*

206–207 XVII. *Why two connected Sets of Rings are of alternate Colours.*

207–208 XVIII. *Of the Cause of the sudden Change of the Colours.*

208–209 XIX. *Of the Place where the different Sets of Rings are to be seen.*

209–210 XX. *Of the Connection between different Sets of Rings.*

211–212 XXI. *To account for the Appearance of several Sets of Rings with the same coloured Centers.*

212–213 XXII. *Of the reflecting Surfaces.*

213–214 XXIII. *Of the transmitting Surfaces.*

214–218 XXIV. *Of the Action of the first Surface.*

218–221 XXV. *Of the Action of the second Surface.*

221–222 XXVI. *Of the Action of the third Surface.*

222 XXVII. *The Colour of the reflecting and transmitting Surfaces is of no consequence.*

222–225 XXVIII. *Of the Action of the fourth Surface.*

225 XXIX. *Considerations that relate to the Cause of the formation of concentric Rings.*

226 XXX. *Concentric Rings cannot be formed by an alternate Reflection and Transmission of the Rays of Light.*

"One of the most simple methods of obtaining a set of concentric rings is to lay a convex lens on a plain metalline mirror; but in this case we can have no transmission of rays, and therefore we cannot

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have an alternate reflection and transmission of them. If to get over this objection it should be said that, instead of transmission, we ought to substitute absorption; since those which in glass would have been transmitted will be absorbed by the metal, we may admit the elusion; it ought, however, to have been made a part of the hypothesis."

1807 97 226–228 XXXI. *Alternate Fits of easy Reflection and easy Transmission, if they exist, do not exert themselves according to various Thicknesses of thin Plates of Air.* One end of a plain strip of glass rested upon a plain metalline mirror, the other end being separated from the mirror by a thin piece of paper. A lens resting upon the strip of glass gave the primary set of rings, and the secondary set by transmission was seen reflected in the metalline mirror. The rays which convey the secondary set of rings to the eye must have passed through the thin wedge of air; but they exhibited no modification, hence the conclusion.

228-229 XXXII. *Alternate Fits of easy Reflection and easy Transmission, if they exist, do not exert themselves according to various Thicknesses of thin Plates of Glass.* An experiment similar to the preceding, but using a slip of glass with sides not quite parallel.

230–232 XXXIII. *Coloured Rings may be completely formed without the Assistance of any thin or thick Plates, either of Glass or of Air.*

A perforated screen, at the center of curvature of a metal mirror, transmitted a beam of sunlight to the mirror. When hair-powder was strewn in the beam of light, coloured concentric circles were seen about the hole in the screen.

232–233 XXXIV. *Conclusion.* The experiments of the last three articles are regarded as proofs that the theory of Sir ISAAC NEWTON is untenable.

1807 97 260 *Observations on the Nature of the new celestial Body discovered by* Dr. OLBERS, *and of the Comet which was expected to appear last January in its return from the sun.* [This was comet, 1806, II.] By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 4, 1807.

260 As soon as I knew of the discovery of [*Vesta*] I tried to discover its situation.

262 Observations of *Vesta.*

263 No disc has been seen even with a power of 636.

264 *Observations of the expected comet.* It was searched for and found near the expected place by my Sister CAROLINA, Jan. 27.

266 Out of 16 comets which I have examined 14 have been without any visible solid body in their centre, and two had a very ill-defined small central light which might perhaps be called a nucleus, but which did not deserve the name of a disk.

266 Plate XVI. Configurations of *Vesta* and stars.

1808 98 145 *Observations of a Comet made with a view to investigate its Magnitude and the Nature of its Illumination.* [This was comet, 1807, I.] *To which is added an Account of a new Irregularity lately perceived in the apparent Figure of the Planet Saturn.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read April 7, 1808.

145 My observations have been directed to its physical condition only.

146 *Of the Nucleus.* By the nucleus, I mean that part of the head which appears to be a condensed or solid body, and in which none of the very bright coma is included. It follows from this definition that when the nucleus is very small a large telescope is required to show it.

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1808 98 147 *Observations.* (By the method described in *Phil. Trans.*, 1805, p. 53.) The visible disk of the comet is a real one.

147 *Illumination of the Nucleus.* The nucleus is round and of equal brightness all over its disk. Its color is a little tinged with red.

148 *Magnitude of the Nucleus.* It appears larger at first sight than after looking a long while.

148 I put a number of globules of sealing wax at a known distance and viewed them during the day, and remembered their [apparent] magnitudes. The nucleus was compared with these and must have been larger than 2″.47 and less than 2″.77. It was less than the disk of *Jupiter's* satellite III.

150 *Of the head of the Comet.* [Definition of the head.]

151 *Of the Coma of the Comet.* [Definition of the coma.]

151 *Of the tail of the Comet.*
One side of the tail is very well defined; the other, hazy.

152 *Of the Density of the Coma and Tail of the Comet.*
I took notice of many small stars covered by the Coma and tail. [The observations show that the interposition of the coma or tail between a faint star and the eye, dimmed the star.]

153 *Nebulous appearance of the Comet.*

154 *Result of the foregoing Observations:*

156 The real diameter of the nucleus was 538 miles.

156 I computed the phases of the comet (see Fig. 1 and Fig. 2, Plate IV, p. 162) for two dates. Both phases appear to me sufficiently defalcated to prove that the comet did not shine by reflected sun-light only.

157 If these remarks are well founded, we are authorized to conclude that the body of the comet on its surface is self-luminous. Its light is more like starlight than moonlight.

157 The tail and coma are sufficiently dense to obstruct the free passage of starlight; they shine, not by reflection but by their own radiance.

159 If I had met the comet in one of my sweeps as it appeared between Dec. 6 and Feb. 21 I should have put it down as a nebula. Perhaps my lists of nebulæ, then, contain some comets.

159 *Account of a new irregularity lately perceived in the apparent Figure of the planet Saturn.*

160 I have ascribed the flattening of the polar regions to the attraction of the ring. In pursuing my observations I perceived a new irregularity in the figure [of the ball] which I am perfectly sure had no existence the last time I examined the planet.

160 *Observations* [of the flattening in high latitudes] 1807, June 16, I perceived it; it was independently drawn by my son, JOHN HERSCHEL.

161 Dr. WILSON, late of Glasgow, sent me a drawing containing the same features made with one of my 7-foot reflectors at Hampstead.

162 Explanation of the "illusion" by refraction of the light from the body of *Saturn* in the atmosphere of the ring.

163 The ring has an atmosphere (see *Phil. Trans.*, 1790, p. 7).

1809 99 259 *Continuation of Experiments for investigating the Cause of coloured concentric Rings, and other Appearances of a similar Nature.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read March 23, 1809.

259-260 XXXV. *Cylindrical Curves produce Streaks.*

261 XXXVI. *Cylindrical and spherical Surfaces combined produce coloured elliptical Rings.*

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1809 99 261-262 XXXVII. *Irregular Curves produce irregular Figures.*

XXXVIII. *Curved Surfaces are required for producing the coloured Appearances at present under consideration.*

263 XXXIX. *Coloured Appearances cannot be produced between the plain Surfaces of two parallel Pieces of Glass applied to one another.*

This conclusion is derived from the observation that colours appear between two such glasses only when they are pressed together with considerable force; but such pressure necessarily produces distortion of form in the glasses.

264-265 XL. *Of the Production of coloured Appearances.*

265 The colours contained in white light may be separated by reflection, as well as by refraction. The production of the blue bow at the limit of total reflection, as described by Sir ISAAC NEWTON, is an instance of this effect.

266-268 XLI. *Particulars relating to the Newtonian prismatic blue Bow.*

A description of the phenomenon, with a calculation of its place and breadth in a particular case.

268-272 XLII. *Account of a prismatic red Bow.*

268 This consists of red, orange, yellow, and some green rays, the red colour being very predominant. To see the red bow, an observer should place himself in the open air, and, standing with his back within a few feet of some wall or building, hold the sides of an equilateral prism flat over his eyes, and look upwards to an altitude of about 30° at the heavens.

269 Calculations relating to this bow.

270-271 Method of projecting the bow.

272-274 XLIII. *Of a sudden Change of the Colours of the Bows.*

272 If a right-angled prism be laid down on a sheet of white paper before a window, and the eye be placed in the proper position for seeing the blue bow, we may instantly transform it into red one by covering the side of the prism which is toward the incident light with a slip of pasteboard.

273 Relative positions of red and blue bows.

274-276 XLIV. *Of Streaks and other Phenomena produced from the prismatic blue and red Bows.*

These may be produced by applying a surface of glass or metal to that surface of the prism which produces the one or the other bow.

276-279 XLV. *Explanation of various Appearances relating to prismatic Bows.*

280-281 XLVI. *The first Surface of a Prism is not concerned in the Formation of the blue Bow, nor of the Streaks that are produced by a plain Glass applied to the efficient Surface.*

281-284 XLVII. *The Streaks which may be seen in the blue Bow contain the colours of both the Parts of the prismatic Spectrum, by the critical separation of which the Bow is formed.*

282 List of colours observed in streaks.

284-291 XLVIII. *On the Formation of Streaks.*

This is an effort to determine by calculation some of the features of the phenomenon under the supposition that the streaks are produced by a reflection, at the surface of the glass plate, of the light transmitted by the prism near the critical angle.

291-292 XLIX. *Prismatic Bows, when seen at a Distance, are straight Lines.*

292-294 L. *The colours of the Bow-streaks owe their Production to the Principle of the critical Separation of the different Parts of the prismatic Spectrum.*

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1809 99 294–298 LI. *A Lens may be looked upon as a Prism bent round in a circular Form.*

299–302 LII. *The critical separation of the Colours, which takes place at certain Angles of Incidence, is the primary cause of the Newtonian coloured Rings between Object-glasses.*

300–301 A comparison of the similarities presented by the phenomena of the rings and those of the bows, modified by a reflecting plate in contact with the effective surface of the prism.

302 LIII. *Remarks relating to the Newtonian alternate Fits of easy Reflection and easy Transmission.*

[Dated] Slough, near Windsor, December 9, 1808.

Plates XII, XIII, XIV.

1810 100 149 *Supplement to the First and Second Part of the Paper of Experiments for Investigating the Cause of Coloured Concentric Rings between Object-glasses, and other appearances of a similar nature.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read March 15, 1810.

149–150 A statement of the object of this supplement, and a discussion of the distinctions between the red and blue bows.

151–153 LIV. *Supplemental Considerations, which prove that there are two primary prismatic Bows, a blue one and a red one.*

154–157 LV. *Illustration of the Dependence of the Streaks of both Bows upon the critical Separation.*

157–159 LVI. *Illustration of the dependence of Rings, seen in a Prism, upon the critical Separation.*

159–161 LVII. *Remarks on Colours supposed to be produced by thin Plates or Wedges of Air.*

A repetition of the experiment of the 39th Article slightly modified. Two slips of plain glass touching at one end were separated at the other by a single fibre of silk. It is concluded that the phenomenon of coloured streaks seen near the line of contact is so well accounted for by the 35th Article that it would not be philosophical to ascribe them to plain surfaces.

161–163 LVIII. *Illustrating Remarks on the Intention of the 14th Figure, explained in the 48th Article of my Paper.*

164–166 LIX. *Experiments on the multiplying Power of Surfaces, in contact, which modify the form of prismatic Appearances.*

166–168 LX. *Of the breadth of the Streaks compared to that of the Bows, and the cause why they must take up a broader space than the Bows from which they are derived.*

169–177 LXI. *Of the Manner in which Rays that are Separated by critical reflection or Intromission come to the Eye.*

Plates V, VI.

1811 101 269 *Astronomical Observations relating to the Construction of the Heavens, arranged for the purpose of a critical examination, the result of which appears to throw some new light on the Organization of the Celestial bodies.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read June 20, 1811.

332 "*Synopsis of the Contents of this Paper.*"

[The following analysis is by HERSCHEL himself and has served as a model to us.]

272 Diffused nebulosity exists in great abundance.

275 Observations of more than one hundred and fifty square degrees of it.

277 Its abundance exceeds all imagination.

Nebulous matter consists of substances that give out light, which may have many other properties.

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1811 101 278–281 Nebulous diffusions contain both milky nebulosity, and such as from its faint appearance may be mistaken for resolvable.

278–279 The range of its visibility is confined to very moderate limits.

280 The purpose for which such great abundance of nebulosity may exist deserves investigation.

282 Either greater depth or greater compression of the nebulous matter may occasion greater brightness.

284 Condensation will best account for greater brightness.

The condensation of the nebulous matter ascribed to gravitation.

285 When a nebula has more than one preponderating seat of attracting matter, it will probably in time be divided.

This conception is supported by the appearance of double nebulæ.

286 Their double appearance can be no deception.

Their nebulosity is derived from one common stock.

290 This opinion is supported by the remarkable situation of nebulæ.

292 Which may be seen in Mr. BODE's *Atlas Cœlestis.*

293–296 The real form of the nebulous matter of which nebulæ are composed may be inferred from their figure.

299 The form of the nebulous matter of round nebulæ is globular.

This form is caused by gravitation.

302 The central brightness of nebulæ points out the seat of attraction.

The effect of attraction on the form of the nebulous matter depends on its original expansion, on the time of the action, and on the quantity of the attracting matter.

305 III different stages of condensation pointed out.

306 Comets may be highly condensed nebulæ.

307 Progressive condensation takes place.

308 Concentric brightness as well as globular form indicates the general gravitation of the nebulous matter.

Progressive condensation may be seen in the formation of nuclei

309–310 Nebulous matter is probably capable of being consolidated; the act of shining proves it to have chemical properties.

It will stop light, and is partly opaque.

311 Queries relating to the subsidence of the nebulous matter, the zodiacal light, and the cause of rotatory motion.

313 Some part of the nebulous matter is probably elastic.

313 The uniform light of nuclei, and of much condensed nebulæ, proves that the nebulous matter is considerably opaque.

314 When the nebulous matter assumes hardness, the progress of condensation will be impeded.

315 Three indications of the compression of the nebulous matter.

Planetary appearance arises from superficial lustre.

316 High degree of condensation of the nebulous matter.

A still higher degree of condensation.

318 In common good telescopes planetary nebulæ cannot be distinguished from stars.

Perhaps they may in the end be so condensed as actually to become stars.

319 The nebulous matter in a cubical space of 10′ will admit of a condensation of two trillion and 208 thousand billion times before it can go into the compass of a globe of the diameter of our sun.

Planetary nebulæ have a rotatory motion on their axes.

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The original eccentricity of the nebulous matter of a nebula may be the physical cause of the rotatory motion of celestial bodies.

1811 101 320 The nebulous star in *Orion* is fictitious.

321 Two out of three nebulous stars in *Orion* have lost their former nebulous appearance.

Their fictitious appearance was owing to a dispersion of their light in passing through nebulous matter.

322 The faintest appearance of the nebulosity in *Orion* is perhaps not further from us than the stars of the third or second magnitude; the brightest part is therefore probably not so far.

323 In thirty-seven years the nebulosity of this nebula has undergone great changes, and much greater since the time of HUYGHENS.

324 Nebulæ are not permanent celestial bodies.

325 Additional proof of the opacity of the nebulous matter.

325 Very distant nebulosities which cannot be seen in a state of diffusion may become visible when condensed into separate nebulæ.

327 Conversion of planetary into bright stellar nebulæ, into stars with burs, or stars with haziness.

329 Conversion of more distant ones into faint stellar nebulæ, into stars with burs or with faint chevelure.

When it is doubtful whether an object is a star or a nebula, it may be verified by an increase of magnifying power.

330 When the object is very like a star it becomes difficult to ascertain whether it is a star or a nebula.

When we cannot ascertain whether the doubtful object is a star or a nebula, of which several instances are given, the similitude is as great as any we can expect; for were it greater there could be no doubt.

336 Postscript.

[Dated] Slough, near Windsor, May 23, 1811.

WILLIAM HERSCHEL.

336 Plates IV & V; 42 figures of nebulæ.

1812 102 115 *Observations of a Comet, with remarks on the Construction of its Different Parts.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read December 19, 1811. [This was Comet 1811, I.]

115 I have examined all the parts of the late comet with a scrutinizing attention by telescopes of every degree of requisite light, distinctness, and power. I have made so many observations that I shall only give a selection of such as were made under the most favorable circumstances.

115 *The Planetary Body in the Head of the Comet.*

Where with the naked eye I saw a luminous appearance not unlike a star, with a telescope I found that this spot, which some might call a nucleus, was only the head of the comet.

116 Within its densest part was an extremely small bright point entirely distinct from the surrounding glare. Its contour was certainly not otherwise than round, yet I could but very seldom perceive it definedly to be so.

116 I examined this point with various magnifiers on a 10-feet telescope. With 169 it was about 1″.39 in diameter.

117 With 600 it was between 1″.06 and 0″.68. The sealing-wax globules were viewed the morning after the observation as well as the morning before. [See *Phil. Trans.*, 1808, p. 145.]

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1812	102	118	*The apparent and real Magnitude of the Planetary Body.* I call its apparent diameter 0″.775; that is, its real diameter was about 428 miles.
		118	*The Eccentricity and Color of the planetary Body.* The planetary body was eccentric in the head.
		119	The color was of a pale ruddy tint like that of such equally small stars as are inclined to red.
		119	*The Illumination of the Planetary Body.* We may infer [from observations] that it was visible by rays emitted from its own body.
		119	*The Head of the Comet.*
		120	[Description of the head.]
		120	*The Color and Eccentricity of the Head.* The color in every one of my telescopes was greenish or bluish green.
		121	The head was eccentric; it deviated towards the sun.
		121	*The Apparent and Real Magnitudes of the Head.* The real diameter of the head was about 127,000 miles.
		122	*A Transparent and Elastic Atmosphere about the Head.* I saw stars through it; it was thus transparent. Its elasticity may be inferred from its circular form.
		122	*The extent of the Cometic Atmosphere.* It was more than 507,000 miles in diameter; its real extent far exceeds this.
		122	*The Bright Envelope of the Cometic Atmosphere.*
		123	*The Figure, Color, and Magnitude of the Atmosphere.* Its shape was circular; it reached nearly half way round the head of the comet, and divided into two streams, one on each side of the head. The color had a strong yellowish cast. Its real diameter must have exceeded 643,000 miles.
		123	*The Tail of the Comet.* It was, Oct. 15, 23½° long.
		124	*The greatest real length of the Tail.* It must have been upwards of 100,000,000 miles.
		124	*The Breadth of the Tail.* It was, Oct. 12, nearly 15,000,000 miles.
		125	*The Curvature of the Tail.* This was subject to variations.
		125	*The general appearance of the Tail.*
		126	The tail had two branches. [See observations.] November 9 the tail of the comet being near the Milky Way, the appearance of one compared to the other was perfectly alike.
		127	*The return of the Comet to the Nebulous Appearance.* As the comet went further from the earth I had reason to suppose that all the still visible phenomena of body, head, atmosphere, envelope, and tail would soon be reduced to the semblance of a common globular nebula. And this, not only from its increasing distance but by the actual physical changes which I observed in the construction of the comet.
		127	*The gradual vanishing of the Planetary Body.*
		128	*The disappearance of the transparent part of the Atmosphere under the cover of the scattered light of the contracted Envelope.*
		129	*Uncommon Appearances in the Dissolution of the Envelope.* One, two, and three streams seen in it at different times.
		130	*Uncommon Variations in the Length of the Streams.*
		131	*Alterations in the Angle of the Direction of the Envelope.*

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312	102	131	*The shortening of the Tail.*
		132	*Increasing Darkness between the Streams that enclose the Tail.*
		133	*Of the real construction of the Comet, and its various Parts.*
		133	The form of the planetary body containing the solid matter of the comet is globular.
		133	The transparent cometic atmosphere is also globular.
		134	The envelope must have been an inverted hollow cone terminating at its vertex in an equally hollow cap nearly hemispherical.
		134	This hemispherical cap was comparatively thin.
		135	The construction of the envelope explained.
			The luminous matter as it arises from the envelope, of which it is a continuation, is thrown a little outwards and assumes the appearance of two diverging bright streams; but if the source from
		136	which they rise be the circular rim of a hollow hemispherical shell the luminous matter in its progress upwards can only form a hollow cone.
		135	The feebler light of the tail between the streams is due to the thinness of the matter in the middle of the hollow cone through which we look.
		136	*Of the Solar agency in the production of Cometic Phenomena.*
		137	As a comet approaches perihelion it is [more] exposed to the action of the solar rays, which can produce light, heat, and chemical effects. Their influence on this comet has produced an expansion. The way these effects have been produced may be supposed to have been as follows:
		137	The matter in the head of the comet would be dilated by the action of the sun, chiefly in that hemisphere of the head nearest the sun; and, being more increased in this direction than the other, it would become eccentric when referred to the situation of the body of the comet. The head being what draws our greatest attention, the planetary body would appear eccentrically situated.
		137	The nebulous matter which, when the comet is far from perihelion, is probably spherical, would, near perihelion, be rarefied and rise to a certain level. In this situation we have had an opportunity of seeing the transparent atmosphere, which, but for the suspension of the nebulous matter, we might never have discovered.
		138	The brilliancy and color of the envelope are proofs of the continued action of the sun, and if we suppose the attenuation of the luminous matter, already very rare, to be carried on, its particles will gradually recede from the hemisphere exposed to the sun and ascend towards the region of the fixed stars. Some such operation must have been carried on.
		138	A whole hemisphere of it being exposed to the sun, it must ascend equally everywhere all round this and become a hollow cone.
		139	The luminous matter ascending in the hollow cone received no addition to its quantity from any other source but the exposed hemisphere.
		139	The tail, near the end, must have been rarefied in an extreme degree.
		139	The vacancy occasioned by the escape of the nebulous matter was probably filled up, either from the opposite hemisphere or by a rotation of the comet about an axis.
		139	That such a process took place seems to be supported by observation.
		140	A rotatory motion of the comet would explain the variation in the lengths of the two branches of the tail.

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1812	102	140	*Of the result of a Comet's Perihelion Passage.*
			The quality of giving out light is immensely increased by an approach to the sun.
		141	The act of shining denotes a decomposition in which at least light (and perhaps many other elastic volatile substances) is given out. I look upon a perihelion passage in some degree as an act of consolidation.
		141	If this idea be admitted, may we not conclude that the consolidation of the comet of 1807, when at perihelion, had already been carried to a much higher degree than that of the present one, by some former approach to our sun, or to other similar celestial bodies, such as we have reason to believe the fixed stars to be?
		142	It is probable that comets may pass around other suns than ours.
		142	Have we not reason to suppose that the comet of 1807 was comparatively a much older comet?
		142	Should the idea of age be rejected, we may suppose that the comet of 1811 since the time of some former perihelion passage may have acquired a quantity of "*unperihelioned* matter" by passing through extensive strata of nebulosity.
		142	I think it not unlikely that the matter of comets is originally nebulous. It may possibly happen that highly condensed nebulæ may be drawn towards the nearest celestial body of the nature of our sun, and, after their first perihelion passage round it, proceed towards some other similar body, and finally may come into the regions of our sun, where at last we perceive them as comets.
		143	The brilliant appearance of our comet may be ascribed either to its having but lately emerged from a nebulous condition, or to its having carried off some [foreign] nebulous matter. The first case will lead us to conceive how planetary bodies may begin to have an existence; the second how they may increase and grow up to maturity.
			WM. HERSCHEL.
			[Dated] Slough, near Windsor, December 16, 1811.
1812	102	229	*Observations of a second Comet, with Remarks on its Construction.* [Comet 1811, II.] By WILLIAM HERSCHEL, LL. D., F. R. S. Read March 12, 1812.
		229	I call this the *second* comet; the other of this year the *first*.
			The Body of the Comet.
		231	The nucleus was 5″.2744 in diameter.
		232	The real diameter of its nucleus cannot be less than 2,637 miles.
		232	*The chevelure of the Comet.*
		233	*The Tail of the Comet.* Its length on January 20 must have been about 659,000 miles.
		233	*Remarks on the Construction of the Comet.*
		234	When the two comets are compared they are found to be extremely different.
		234	The light of the second comet is probably reflected from the sun. The nucleus of the comet is surrounded by an elastic atmosphere, which is transparent.
		235	The little extent and extreme faintness of the tail might be ascribed to the great perihelion distance of the comet if the comparative view of the comets of 1807 and 1811 in my last paper did not prove

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that the effect of the solar agency depends entirely upon the state of the nebulous matter of which the comet is composed. This second comet had probably but little *unperihelioned* matter.

12 102 236 If, then, the effect of the sun on comets is more or less conspicuous, according to the amount of unperihelioned nebulous matter which they contain, we may arrange these celestial bodies in a certain order of consolidation, from which, in the end, a considerable insight into their nature and destination may be obtained.

236 For example, the comet of this paper is of such a construction that it was but little more affected by its perihelion passage than a planet would have been. It was in a very advanced state of consolidation.

237 That of 1807 was more affected, and, although considerably condensed, conveyed a great quantity of nebulous matter to the perihelion passage. That of 1811 contained, with little solidity, a most abundant portion of nebulous matter.

4 104 248 *Astronomical Observations relating to the Sidereal part of the Heavens and its Connection with the Nebulous part; arranged for the purpose of a critical examination.* By WILLIAM HERSCHEL, LL. D., F. R. S. Read February 24, 1814.

In the memoir on the nebulous part of the heavens [*Phil. Trans.* 1811] I have endeavored to show the probability of a very gradual conversion of the nebulous matter into the sidereal appearance. This paper refers to the sidereal part of the heavens.

249 I. *Of stars in remarkable situations in regard to Nebulæ.*

Surmise that nebulæ may have considerable proper motions. Necessity of caution in such conclusions. Five stars in such situations.

250 II. *Of two stars with nebulosity between them.*

19 instances of such connection are given; in the memoir of 1811, 139 double nebulæ joined by nebulosity were noted.

251 Should we not surmise that possibly these stars had formerly been highly condensed nebulæ like those that had been mentioned, and were now by gradually increasing condensation turned into small stars; and may not the nebulosity still remaining show their nebulous origin? Also as we have over 700 double stars free from nebulosity, many of which are probably at no great real distance from us, it seems as if we might have these double objects in three different successive conditions. First, as nebulæ; next as stars with remaining nebulosity; and lastly, as stars completely free from nebulous appearance.

251 III. *Of stars with nebulosity of various shapes attached to them.*

252 Fourteen such objects noted.

Now, if we admit a contact between these nebulæ and the stars, it deserves to be remarked that stars in the situation of these fourteen cannot have been formed from their adjoining nebulosities; for a gradual condensation of the nebulous matter would have been central; whereas the stars are at the extremity of the nebulæ. Their connection is then due to some motion either of the star or of the nebulæ. If the nebulosity should subside into the star, it would give an idea of the *growth* of a star.

253 IV. *Of stars with nebulous branches.*

Three cases noted of a connection between stars and nebulæ, and reference made to *Phil. Trans.*, 1811, pp. 301–311, for further examples.

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1814 104 254 The idea of a nebula with a nucleus which gradually assumed the lustre of a star is more probable than the fortuitous central meeting of a star and nebula.

V. *Of nebulous stars.*

Thirteen are noted—see also *Phil. Trans.*, 1791, p. 71.

255 Nebulous stars are not only connected with a nebulosity, which, from its great regularity, might be taken for an atmosphere, but also with the luminous appearances belonging to the nebulous matter which is so widely expanded in various regions of the heavens.

What has been said of the gradual condensation of the nebulous matter in the case of extended nebulæ, is supported by a much greater number of nebulosities in a spherical form. [See *Phil. Trans.*, 1811, pp. 301–8.] 322 cases are there mentioned, in which the fact of the gradual condensation is rendered so evident as not to admit of a doubt.

256 Nebulous stars only differ from round nebulæ containing a nucleus in the degree of condensation.

256 VI. *Of Stars connected with extensive windings of nebulosity.*

Three cases noted. The nebulosity which has been shown to be connected with stars, may be fully proved to be of the same nature as the general mass of nebulous matter.

Stars of this class are in a condition of growth.

257 Possibility that stars were originally formed by a condensation of the nebulous matter.

We may conceive both the generation and growth of stars to be the legitimate effects of the law of gravitation, to which the nebulous matter is proved by observation to be subject.

VII. *Of small patches consisting of Stars mixed with nebulosity.*

Thirty-seven cases noted.

The connection may be only apparent—admitting it to be real:

1st, it may happen that the nebulosity still mixed with the stars is some remaining unsubsided part of that from which they were formed; or, 2d, the union of stars and nebulosity may have been affected by the motion of either the stars or the nebulosity.

258 Such motions do take place. Nebulæ are subject to great changes in their appearance, as the nebula of *Orion.* [*Phil. Trans.*, 1811, p. 320.]

259 Every nebulosity which is carried into the region of a small patch of stars will probably be gradually arrested and absorbed by them, and the *growth of stars* thus continued.

VIII. *Of objects of an ambiguous construction.*

Clusters of stars at a great distance may assume a nebulous appearance. [*Phil. Trans.*, 1811, p. 270.]

Telescopes of gradually increasing space-penetrating powers show certain objects successively as nebulæ, mixtures of nebulosity and stars, and as true clusters; other objects, so viewed, increase in brightness, and the nebulosity becomes more uniformly united and of a milky appearance, and these are purely nebulous.

260 Definition of *ambiguous* objects, their classification and examples. Seventy-one such noted in four classes.

Class 1. Seven objects, which may be supposed to consist of stars, but where observations leave it doubtful.

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1814 104 261 *Class* 2. Twenty-six objects of round or nearly round figure. The round figure of these show them to be *globular*. They must either be in a condensed state purely nebulous, or else, if consisting of stars, they must be in an advanced order of compression, and only appear nebulous on account of their very great distance from us.

A middle state between the progressive condensation of a globular nebula and a cluster of stars can have no existence, because a globular nebulosity when condensed can only produce a single star. A globular cluster may, however, intercept a mass of nebulous matter in motion, in which case the nebulosity must soon assume the form of the cluster, and will finally be absorbed by it.

Class 3. Twenty-six easily resolvable objects.

262 *Class* 4. Twelve objects, probably clusters.

IX. *Of the sidereal part of the Heavens.*

Intimate connection between the nebulous and sidereal condition.

263 Stars of first magnitude. [See *Phil. Trans.*, 1785, p. 68.]

264 Prismatic analysis of the light of *Sirius, α Orionis, Procyon, Arcturus*, *Aldebaran and α Lyræ.*

265 X. *Of the aggregation of stars.*

Star-gauges prove that the stars are not equally distributed over the celestial regions. [See *Phil. Trans.*, 1785.]

Forming clusters. This tendency to clustering is chiefly visible in places extremely rich in stars. Its greatest effects will then be in and near the milky way.

266 The twenty objects referred to are not given as instances of the actual formation of clusters, but merely to draw attention to a seemingly aggregating arrangement. Fifteen of these are in the milky way and five are near it.

266 XI. *Of irregular clusters.*

Clusters in very rich parts of the heavens are generally of irregular form and imperfectly collected. One hundred and twelve such ob-
267 jects are referred to; eighty of size not noted, fifty-three of these in the milky way, eighteen near it, nine at a distance from it. Also thirty-two irregular clusters from 2′ to 30′ in diameter; of these twenty-two are in the milky way and ten near it.

267 The great number of clusters in these two collections is not only an indication that they owe their origin to a clustering power residing in the centre; but the still remaining irregularity of their arrangement additionally proves that the action of the clustering power has not been exerted long enough to produce a more artificial construction.

268 XII. *Of clusters variously extended and compressed.*

Fifteen extended clusters named; twelve in the milky way, three near it. Their descriptions show that the power which has drawn the stars together has acted under different circumstances in the several cases.

269 XIII. *Of clusters of stars of a peculiar description.*

Six such objects named: one in the milky way, three near it, two at a distance from it.

271 XIV. *Of differently compressed clusters of stars.*

I have hitherto only considered the arrangement of stars in clusters with a view to point out whether they are drawn together by a clustering power in the same manner as the nebulous matter has

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been proved to be condensed by a gravitating principle; but in the forty-one clusters of the following two collections we shall see that it is one and the same power uniformly exerted which first condensed nebulous matter into stars and afterwards draws them together into clusters, and which, by a continuance of its action, gradually increases the compression of the stars which form the clusters. The first collection has thirty-three considerably compressed clusters, seventeen in the milky way, fifteen near it, and one at a distance. The second collection contains eight clusters, highly compressed, five in the milky way, two near it, and one at a distance.

1814 104 272 XV. *Of the gradual concentration and insulation of clusters of stars.*
The existence of a clustering power is nowhere so visibly pointed out as in the thirty-nine clusters given in the following collection: Twenty-one of these are in the milky way, seven near it, and eleven at a distance.

273 XVI. *Of globular clusters of stars.*
Fourteen such objects noted: One in the milky way, four near it, and nine at a distance from it.

274–7 [Detailed accounts from observing books of M. 72; M. 2; M. 5; M. 56; M. 80; M. 13; M. 3; M. 15; M. 79; M. 19; M. 53.]

278 XVII. *Of more distant globular clusters of stars.*
The following eleven objects are so like those of the foregoing collection that I have called them miniatures of the former. Five of these are in the milky way, one near it, and five at a distance. Detailed descriptions given.

279 I have supposed the clusters of this class to be at a greater distance from us than those of the preceding collection, because the stars of which they are composed are more minute than those of the clusters of which I have called them miniatures; their compression is also closer, and the size of the whole is much contracted, all of which particulars are readily explained by admitting them to be more distant. This argument, however, does not extend so far as to exclude a real difference which there may be in different clusters, not only in the size, but also in the number and arrangement of the stars.

XVIII. *Of still more distant globular clusters of stars.*

280 It has frequently happened that I saw three objects in succession, the first of which was a brilliant globular cluster of stars, the second a miniature of the former in which the stars could just be perceived, and the third in every respect a similar miniature of the second, as the second was of the first, but in which the stars, though suspected, were no longer to be distinguished. Five such objects given, all in the milky way.

XIX. *Of a recurrence of the ambiguous limit of observation.*

281 It has already been shown [VIII, p. 259] that in passing from faint nebulosity to the suspected sidereal condition we cannot avoid meeting with ambiguous objects, and the same critical situation will again occur, when, from the distinctly sidereal appearance, we endeavor to penetrate gradually further into space.
The effects of clustering power have been gradually traced from the first indication of clustering stars through irregular as well as through more artificially arranged clusters up to the beautiful globular form.

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The extended views I have taken in this and in my former papers of the various parts that enter into the construction of the heavens have prepared the way for a final investigation of the universal arrangement of all these celestial bodies in space. The *scale* is still wanting by which distances are to be measured.

314 104 282 XX. *Of the breaking up of the Milky Way.*

Its whitish tinge has been proved by star-gauges to arise from accumulated stars. It does not now consist of equally scattered stars.

283 One hundred and fifty-seven instances have been given of clusters situated within the milky way. Sixty-eight more are in the borders. Now, since the stars of the milky way are permanently exposed to the action of a power whereby they are irresistibly drawn into groups, we may be certain that from mere clustering stars they will be gradually compressed through successive stages of accumulation till they come up to what may be called the ripening period of the globular form, and total insulation; from which it is evident that the milky way must be finally broken up and cease to be a stratum of scattered stars.

The state into which the incessant action of the clustering power has brought it at present is a kind of chronometer that may be used to measure the time of its past and future existence; and although we do not know the rate of going of this mysterious chronometer, it is

284 nevertheless certain that since the breaking up of the milky way affords a proof that it cannot last forever, it equally bears witness that its past duration cannot be admitted to be infinite.

This paper is accompanied by Plate IX, p. 284, with 17 figures.

Fig. 1 = H. v, 46.	Fig. 7 = H. iv, 42.	Fig. 13 = H. viii, 44.
2 = H. iii, 67.	8 = H. iv, 69.	14 = H. viii, 4.
3 = H. ii, 706,	9 = H. iv, 33.	15 = H. vi, 36.
4 = H. i, 143.	10 = H. iii, 697.	16 = H. vi, 5.
5 = H. iv, 4.	11 = H. ii, 101.	17 = M. 72.
6 = H. iv, 35.	12 = H. ii, 500.	

15 105 293 *A series of observations of the satellites of the Georgian planet, including a passage through the node of their orbits; with an introductory account of the telescopic apparatus that has been used on this occasion; and a final exposition of some calculated particulars deduced from the observations.* By William Herschel, LL. D., F. R. S. Read June 8, 1815.

293 A telescope suitable to examine these faint objects must possess the double power of magnifying and penetrating into space.

294 The *effective* magnifying power defined.

A 10-foot reflector, even with its highest powers, will not show these objects.

295 The machinery of my 20-foot telescope is so complete that I have been able to take up the planet at an early hour in the evening and to follow it for 7, 8, or 9 hours successively. The 40-foot telescope has not been always used because time is required for preparations. The temperature is often too changeable; its use requires 2 workmen, beside the assistant at the clock and writing-desk.

296 The 20-foot can be pointed on the planet with everything adjusted in 10 minutes.

206 It has constantly been a rule with me not to observe with a larger instrument when a smaller would answer.

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I have two mirrors for the 20-foot always ready, and my observations are never interrupted by accidents, which often happen to large mirrors, such as greatly injure their polish.

1815 105 296 In these delicate observations no double eye-glass should be used, as we have a waste of light at four surfaces instead of two.

297 The hole through which the rays pass to the eye should be much larger than the diameter of the optic pencils and considerably nearer the glass than their focus, for the eye ought on no account to touch the eye-piece.

297 With regard to the eye-glasses when merely the object of saving light is considered, I can say from experience that concaves have greatly the advantages of convexes, and they give also a much more distinct image. This fact I established by repeated experiments about 1776. For the cause of the superior brightness and sharpness of the image which is given by concaves we must probably look to the circumstance of their not permitting the reflected rays to come to a focus. Perhaps a certain mechanical effect, injurious to distinctness, takes place at the focal crossing of rays in convex lenses.

297 [Foot-note.] [An experiment to test this described. It was inconclusive.]

298 The satellites were discovered with a magnifying power of 157 only.

299 Magnifiers of 300, 460, 600, and 800 have been used, according to the conditions of the mirror, atmosphere, etc. On particular occasions 1,200 was used, and 2,400, 3,600, and 7,200 have been used to scrutinize the closest neighborhood of the planet. The known satellites began to be nebulous with these powers.

299 In the following observations the positions of the satellites have been determined in 3 ways: Coarse estimations, aided by diagrams; more careful ones, aided by a wire in the focus of the eye-glass; and micrometer measures.

301 Distances were more difficult to measure than angles of position.

302 The following observations are given in the order of the time they were made. They contain everything that relates to the two large satellites and to the researches for detecting additional satellites.

That such there are I have no doubt.

303 After each observation is given an "identification" which shows by computation the places of the known satellites.

304 The configurations made at the time of observation are not given. They generally contained the planet, its satellites and some of the neighboring stars, especially those that were in the path of the planet.

304 *Observations of the satellites of the Georgian planet, accompanied by a theoretical determination of their situation, whereby their identity may be ascertained.* [From 1787, Jan. 11, to 1810, May 25.]

322 [Foot-note.] Telescopic vision in windy weather is generally very perfect.

343 *Investigation of several particulars deduced from the foregoing observations, with an exposition of the method by which they have been obtained.*

344 *The place of the ascending node, the inclination of the orbits and the retrograde motions of the satellites determined.*

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815 105 345 *Consideration of the principles by which the periodical revolution of the satellites may be obtained from the observed angles of position.*

348 *The periodical revolutions of the satellites determined.*

350 The *first satellite* [*Titania*] makes a synodical revolution in $8^d\ 16^h\ 56^m\ 5.2^s$ and the *second* [*Oberon*] in $13^d\ 11^h\ 8^m\ 59^s$.

351 *Explanation of the identifying method.*

355 I. With the light of my 20-foot telescope the first satellite generally becomes invisible at a distance of [18″] from the planet; and

II. The second at about [24″].

III. An interior satellite cannot be seen two nights in succession.

356 IV. Exterior satellites that are very faint when at their greatest elongation can hardly ever be seen at any other time when the orbits are contracted.

V. [*Titania*] is probably larger than [*Oberon*].

VI. Both are subject to great variations of light [not owing to the changeable clearness of the air].

VII. This may be due to a rotation on their axes, or from atmospheres.

VIII. I have supposed the distances of the first and second satellites to be 36″ and 48″ respectively.

IX. The existence of additional satellites has been considered already in *Phil. Trans.*, 1798, p. 59.

358 *An interior satellite.*

359 *Addition* [in regard to an interior satellite].

360 *An intermediate satellite. An exterior satellite;* and *Addition.*

361 *More distant satellites;* and *Addition.*

362 Plate XVI, diagram.

317 107 302 ***Astronomical Observations and Experiments tending to investigate the local Arrangement of the Celestial Bodies in Space and to determine the Extent and Condition of the Milky Way.*** By Sir WILLIAM HERSCHEL, *Knt. Guelp.*, LL. D., F. R. S. Read June 19, 1817.

302 The construction of the heavens can only be known when we have the situation of each body defined by its three dimensions. Of these three the ordinary catalogues give but two, leaving the distance or profundity undetermined.

303 The method of parallaxes has given the distance of the sun, planets, etc. The parallax of the stars has also received attention. With regard to more distant objects, as small stars, compressed clusters, and nebulæ, these methods can give us no assistance.

303 I. *Of the local situation of the stars of the Heavens.*

304 It is evident that we cannot mean to affirm that the stars of the fifth, sixth, and seventh magnitudes are really smaller than those of the first, second, or third, and that we must ascribe the cause of the difference in the apparent magnitudes of the stars to a difference in their relative distances from us. On account of the great number of stars in each class we must also allow that the stars of each succeeding magnitude beginning with the first, are, one with another, further from us than those of the magnitude immediately preceding. The relative magnitudes give only relative distances, and can afford no information as to the real distances at which the stars are placed.

304 II. *Of a standard by which the relative arrangement of the stars may be examined.*

A standard of reference for the arrangement of the stars may be had

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by comparing their distribution to a certain properly modified equality of scattering. The equality which I propose does not re-
1817 107 305 quire that the stars should be at equal distances from each other, nor is it necessary that all those of the same nominal magnitude should be equally distant from us.

305 It consists in allotting a certain equal portion of space to every star, in consequence of which we may calculate how many stars any given extent of space may contain.

This arrangement is explained by means of a figure. Plate XV, Fig. 1.

306 III. *Comparison of the order of magnitudes with the order of distances.*

Comparison of the order of distances by the foregoing scheme with the magnitudes assigned in BODE'S catalogue of 14,144 stars.

308 The result of this comparison is, that if the order of magnitudes could indicate the distance of the stars, it would denote at first a gradual, and afterwards a very abrupt, condensation of them; but that, considering the principle on which the stars are classed, their arrangement into magnitudes can only apply to certain relative distances, and show that, taking the stars of each class, one with another, those of the succeeding magnitudes are farther from us than the stars of the preceding order.

308 IV. *Of a criterion for ascertaining the profundity or local situation of celestial objects in space.*

309 It will be admitted that those stars, the light of which we can experimentally prove to be $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$...... of the light of any certain star of the first magnitude must be 2, 3, 4......times as far from us as the standard star, provided the condition of the stars should come up to the supposed mean state of diameter and lustre of the standard star.

309 V. *Of the equalization of star light.*

309 Star gauging gave rise to an investigation of the space-penetrating power of telescopes.

310 Finding that this might be calculated with reference to the extent of the same power of which the unassisted eye was capable, there always remained a desideratum of some sure method by which this last might be ascertained.

Description of experimental apparatus.

311 Method of limiting apertures described.

313 VI. *Of the extent of natural vision.*

313–8 Experiments on stars made in August and December, 1803, and February, 1814.

314 *Arcturus* has four times the light of α *Andromeda*, *Polaris*, γ *Ursæ*, and δ *Cassiopeæ*. α *Andromeda* is four times as bright as μ *Pegasi*, etc., etc.

316 Table of proportional light of stars of various orders.

318 The distances of clusters cannot be ascertained by the method of equalizing star light.

VII. *Of the extent of telescopic vision.*

319 Experiments which go to show that the diameter of the pupil of the human eye is not more than 0.21 inch, and is greater than 0.17 inch when observing with a telescope. It may be assumed 0.2 inch.

320 VIII. *Application of the extent of natural and telescopic vision to the probable arrangement of the celestial bodies in space.*

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We shall be able to say that a distant celestial object is so far from us, provided the stars of which it is composed are of a size and lustre equal to the size and lustre of such stars as *Sirius*, *Arcturus*, etc.

1817 107 321 The stars of the tenth, eleventh, and twelfth order of distances are not only more compressed than those in the neighborhood of the sun, but, moreover, their compression in different parts of the heavens must be very unequal.

IX. *Of the construction and extent of the milky way.*

322 General description of it.

The sun is within its plane, for to an observer in latitude 60°, when at 100° R. A. the milky way is in the east, it will at the same time be in the west at 280°; while in its meridional situation it will pass through *Cassiopeia* in the Zenith and through the constellation of the Cross in the Nadir.

323–4 Examination of the cluster in the Sword Handle of *Perseus*, with various space-penetrating powers.

325 [Beside the 863 gauges published in *Phil. Trans.*, 1785, p. 221, above 400 more have been taken in various parts of the heavens and are not published.]

326 The twenty-foot telescope cannot fathom the profundity of the milky way.

326 If the stars of the 5th, 6th, and 7th magnitudes cannot be supposed to be gradually of a smaller physical size and brightness than those of the 1st, 2d, and 3d, how much less can a supposition be admitted that would require that the stars which, by a long series of gauging powers, have been proved to make their gradual telescopic appearance should also be gradually of a different construction with regard to physical size and brightness from those which we see with the naked eye?

327 The telescopic breadth of the milky way considerably exceeds the extent which, in our maps, is assigned to it.

328–30 Observations—sweeps—which confirm this.

330 X. *Concluding Remarks.*

What has been said of the extent and condition of the milky way in my papers on the construction of the heavens, with the addition of this attempt to give a more correct idea of its profundity in space, will contain nearly all the general knowledge we can ever have of this magnificent collection of stars.

331 Our sun with all the stars we can see with the eye are deeply immersed in the milky way, and form a component part of it.

WILLIAM HERSCHEL.

[Dated] Slough, near Windsor, May 10, 1817.

1818 108 429 *Astronomical observations and experiments, selected for the purpose of ascertaining the relative distances of clusters of stars, and of investigating how far the power of our telescopes may be expected to reach into space when directed to ambiguous celestial objects.* By Sir WILLIAM HERSCHEL, *Knt. Guelp.*, LL. D., F. R. S. Read June 11, 1818.

429 The method of equalization of star light will show the relative distances of stars; from this a method was explained in *Phil. Trans.*, 1817, by which means the profundity in space of every object consisting of stars can be ascertained as far as the light of the telescope

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suffices. This method may be used to ascertain the profundity of globular and other clusters.

1818 108 430 I. *Of the distance of globular and other clusters of stars.*

General principles to guide in such observations.

431 II. *A series of observations of clusters of stars from which the order of their profundity in space is determined.*

431–51 Observations of H. vi, 7, 9, 10, 11, 12, 17, 20, 26, 35, 38, 41, 63, and of M. 1, 2, 3, 4, 5, 9, 10, 11, 12, 13, 14, 15, 19, 22, 30, 33, 34, 35, 53, 55, 56, 57, 62, 67, 68, 69, 71, 72, 74, 75, 77, 79, 80, 92, 97.

451 III. *Of a method to represent the profundity of celestial objects in space by a diagram.*

470 Fig. 1, Plate xxi, represents such a method applied to the foregoing objects.

460 IV. *Of ambiguous celestial objects.*

An object is often ambiguous when viewed with insufficient optical means, and its nature may be known by increasing this means. Objects ambiguous to the naked eye become known with the 20-foot telescope, and so on.

462 V. *The milky way, at the profundity beyond which the gauging powers of our instruments cannot reach, is not an ambiguous object.*

463 We may conclude that when our gauges will no longer resolve the milky way into stars it is not because it is ambiguous, but because it is fathomless.

463 VI. *Of the assumed semblance of clusters of stars when seen through telescopes that have not light and power sufficient to show their nature and construction.*

464 Observations of various clusters in telescopes of various sizes.

465 Two different principles, the *nebulous* and the *sidereal*, have been observed in the celestial spaces.

Distinguishing characteristics of each.

466 It seems highly probable that some of the cometic, many of the planetary, and a considerable number of the stellar nebulæ, are clusters of stars in disguise.

466 VII. *Of the extent of the power of our telescopes to reach into space when they are directed to ambiguous celestial objects.*

The method of equalizing the light of stars may be applied so as to give an estimate of the extent of this power.

When the united light of a cluster of stars is visible to the [naked] eye, there will be a certain maximum of distance to which the same cluster might be removed, so as still to remain visible in a telescope of a given space-penetrating power; and if the distance of the cluster can be ascertained by the gauging power of any instrument, that will just show the stars of it, the order of the profundity at which this cluster could still be seen as an ambiguous object may be ascertained by the space-penetrating power of the telescope through which it is observed.

467–70 Examples of this method.

470 Plate XXI.

William Herschel.

[Dated] Slough, near Windsor.

VI.—Subject-Index to the scientific writings of Herschel.